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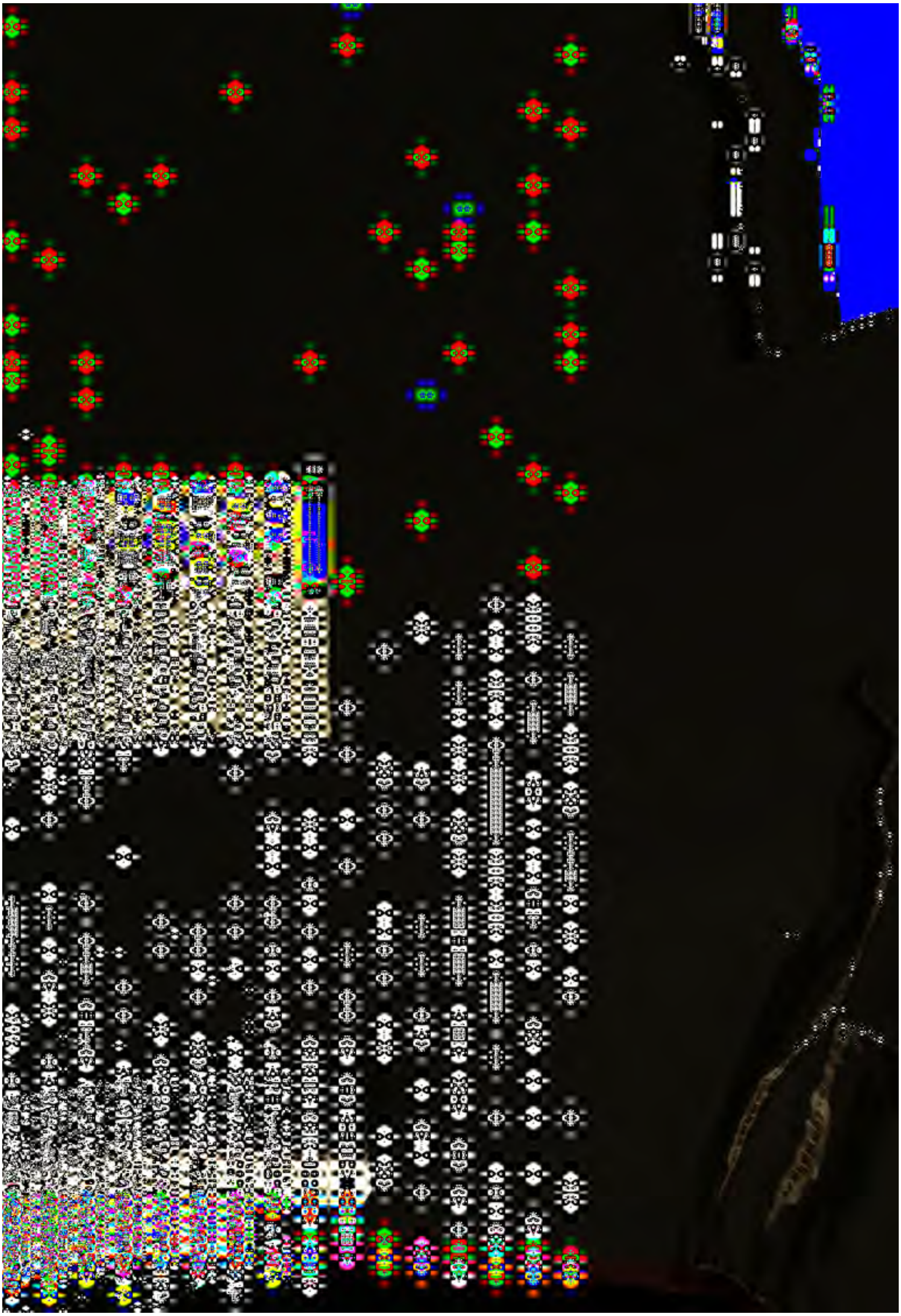

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ENGINE-ROOM PRACTICE.

A HANDBOOK FOR THE ROYAL NAVY AND MERCANTILE MARINE:

TREATING OF THE MANAGEMENT OF THE MAIN AND
AUXILIARY ENGINES ON BOARD SHIP.

BY

JOHN G. LIVERSIDGE, ENGINEER-COMMANDER, R.N.,
A.M.INST.C.E.,
FORMERLY INSTRUCTOR IN APPLIED MECHANICS AND ENGINE DESIGN AT THE
ROYAL NAVAL COLLEGE, GREENWICH; FIRST ASSISTANT TO
CHIEF ENGINEER OF MALTA DOCKYARD.

"No machine yet contrived or hereafter contrivable will ever equal the fine machinery of the human fingers."—RUSKIN, *The Unity of Art.*

FIFTH EDITION, REVISED.

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PREFACE TO THE FIFTH EDITION.

SINCE the publication of the First Edition of this work the Author has been employed on various foreign stations, and in his absence the Publishers have found it necessary to issue three large reprints to meet the constant demand for the book. Recently the opportunity has occurred to thoroughly revise the work, and in this edition much additional matter has been inserted; partly concerning the changes brought about by the successful adoption of Water-Tube Boilers and higher Steam Pressures, and partly on the subject of "repairs" and engine adjustments, concerning which more definite information has been given, accompanied by an increased number of illustrations.

Wherever the information was available, the Author has revised the descriptions given of Auxiliary Machinery, substituting or adding later types of the various classes.

The Article on "The Management of Water-Tube Boilers" has been kindly re-written by Engineer-Captain R. W. Edwards, R.N.; and the Instructions for working the various types, issued by the Lords of the Admiralty, have been included for the convenience of those who may desire to refer to or compare them.

MALTA, *April*, 1906.

PREFACE TO FIRST EDITION.

THE work of collecting and arranging the "practice" detailed in the following pages was undertaken by the Author in consequence of a proposal by Messrs. Griffin, the Publishers. It is hoped that an account of the nature and methods of the work of a marine engineer will be useful to young engineers, who are preparing for, or entering on, their career, and also perhaps to those other officers whose work and responsibilities are so intimately connected with the machinery of a modern steamship.

The Author realises that the "practice" described in this book will not be that which is in use in every case. It is, perhaps, unnecessary to disclaim any pretence of superiority for the methods described; they are merely those which have been successfully used in certain instances. The general lines of the book were laid down to avoid, as far as possible, the subjects fully treated in the standard work written by Mr. Seaton.* It is hoped that the greater space which can be allowed in this work for the description of methods of "Care and Maintenance," and of repairs, will make it a useful supplement to the book mentioned.

Whenever it is not otherwise stated in the text, the methods of treatment applied to the Main Engines and Boilers have been used in vessels of the Royal Navy. The regulations and instructions for Naval Engineers are laid down in the official *Steam Manual;* and this volume is referred to frequently by the letters *S.M.;* it is hoped that everything that follows will be found in accordance with the official orders given therein.

Illustrations of special types of machinery made by certain firms are given, and the Author again thanks those firms for their help. It would require much more than the space available to describe every pattern of such types, and the Author has, therefore, selected those of which he had most experience. The instructions given for the working of these special machines have been compared with those issued by the makers.

In conclusion, the Author desires to express his thanks for, and appreciation of, the information and criticism given him by those engineers to whom he has applied for the results of their experience; and he especially congratulates himself on the co-operation of several officers of the R.N.R.; to which co-operation he is indebted for the Chapter dealing with the conditions of service in leading steamship lines. Such assistance has been, in all cases, given with great goodwill, and the Author feels that without similar help a book on the subject would be of small value.

GREENWICH, *March*, 1899.

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* See *A Manual of Marine Engineering*, by A. E. Seaton; published by Messrs. Charles Griffin & Co., Ltd.

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ENGINE-ROOM PRACTICE.

CHAPTER I.

GENERAL DESCRIPTION OF MARINE MACHINERY.

THE machinery on board ship consists, firstly, of the motor machinery, fitted for propulsion only, and comprising the **main engines**, together with such necessary supplementary engines as the air pumps, circulating pumps, and main feed pumps. These supplementary pumps generally have independent engines driven by steam taken from the steam pipe supplying the main engines. Formerly, the functions of these separate engines were performed by the main engines themselves; but for some time the tendency afloat has been to relieve the main engines of all duties except the single one of propulsion. An exception must be made in the case of the air pump, which is frequently actuated by a rocking beam from one of the main engine crossheads; in the American Navy the air pump is independent.

Secondly, there are the various **auxiliary engines**, which are of two classes:—(*a*) Those fitted to perform various operations formerly effected by manual labour. To this class belong—the steering engine, the capstan engine, the boat-hoist engine, and the winches; the starting engine, the ash hoists, and various others common to the mercantile fleet and warships alike. (*b*) Those fitted for special purposes, according to the character of the ship itself, and due to the advance of Engineering Science. To this class belong the hydraulic and torpedo machinery of warships; and the electric light, refrigerating, and distilling machinery, common also to the Mercantile Marine.

Main Engines.—The almost universal type of main engines fitted in recent practice is the vertical, inverted direct-acting; the cylinders are, generally, vertically above the crank shaft and borne on columns, the feet of which are secured to the transverse engine brackets carrying the crank-shaft bearings. These brackets are often connected by longitudinal frames, of a box or I section. The back and front columns are also sometimes further secured together by transverse rods; especially is this the practice in light machinery, developing high power by means of a short stroke and a high number of revolutions. The longitudinal frames and the transverse brackets are secured to a box framing of plates and angle bars, built up from the main framing of the ship's structure.

The cylinders of the main engines are separate castings, secured together by massive bars running longitudinally; and, in the case of a twin-screw ship, the corresponding port and starboard cylinders are, in many instances, connected athwartships by stays adapted to act as ties or struts. These stays are attached to the mid line bulkhead, which is, as a rule, specially stiffened for this reason. In some warships a strong plate bracket is fitted between the forward end of the engines and the forward engine-room bulkhead; and, in addition, wire rope ties are secured from the after end of the engines to the after bulkhead. These ties are invariably fitted in cruisers and battleships of the English Navy.

The advantages of this type of engine are:—

1. The working surfaces are clearly in view and easy of access for adjustments or removal.

2. The engines require less floor area than the horizontal type, and the overhead space is utilised; a longer stroke can be obtained.

3. The wear and tear of the guide surfaces and piston liners is smaller than in the horizontal type; this is especially important, since to get at a piston ring involves considerable time and labour, whilst smooth working cannot be obtained with the engines out of line. It is due principally to the improved running of the vertical inverted type of engine that the piston speed of marine engines has been increased, and that such engines as those of the torpedo boat destroyers have been rendered possible.

Propulsion.—Steamships which relied mainly on their sailing powers were generally fitted with a single screw, in order to reduce the resistance; many merchant service vessels have only a single screw, for reasons involving simplicity and first outlay. Most of the vessels of the Royal Navy and modern fast "liners" are propelled by twin screws; the main engines are then placed to port and starboard, respectively, in separate engine-rooms divided by a longitudinal bulkhead. Formerly the screws turned outwards when going ahead, so that the starboard propeller was right-handed,* and the port one left-handed; with this arrangement the front of the engines and the starting platforms are on the wing side of the cylinders. Recently this practice has been reversed in the engines of H.M.S. "Terrible," "Powerful," and other vessels, and the propellers have been fitted to turn inwards, so that the port propeller is right-handed and the starboard one left-handed; it follows that the front of the engines and the starting platforms are on the midship side of the cylinders, and, therefore, nearer together. This arrangement is convenient for the engineer of the watch, who, from the water-tight door in the middle line bulkhead, can see nearly all the working parts of both engines, and can more easily supervise the manœuvring of the engines when starting and stopping. It is claimed that the arrangement produces an increased propulsive efficiency.

---

* A propeller is said to be right-handed when, viewed from aft, it revolves clockwise for ahead motion.

The advantages of propulsion by twin screws, as compared with single-screw propulsion, are summed up as follows:—

1. The ship has far greater manœuvring power.
2. The ship can proceed with one set of engines, at a speed approaching three-fourths of full speed, in the event of the other set being disabled.
3. The arrangement lends itself to the subdivision of the engine-room space into water-tight compartments.
4. The propulsive efficiency of twin screws is greater than that of a single screw; because, generally, the augmentation of resistance due to the two propellers is not so great (White's *Naval Architecture*, pp. 545 and 547) as that due to the single propeller.
5. The moving parts of the machinery, including the propeller, are of less size and weight, and the processes of manufacture are facilitated.

Triple screws[*] have been fitted in the United States cruisers "Columbia" and "Minneapolis." The latter is of 8005 tons displacement and 20,860 I.H.P., and attained a speed of 23 knots over a course of 87·7 nautical miles. Commodore Melville, Engineer-in-Chief, United States Navy, compares the performance with that of the twin-screw ships "New York" and "Olympia," and states that the efficiency of propulsion is 67·72 per cent. for the triple-screw ship, and 60·59 and 56·73 for the latter two respectively. The triple screws were adopted for practical considerations of economy, as it was intended to use the centre screw alone at low powers, the side screws being cast free to revolve. The anticipated increase of efficiency has not, however, been realised in practice.*

---

[*] In 1897, the Hon. C. Parsons[*] adopted three shafts—each carrying three screw propellers and driven by a separate steam turbine to propel his experimental boat, the "Turbinia," which, although only 00 feet in length, attained a mean speed of 31 knots. The I.H.P. of the three turbines was 2100, and the shafts revolved at 2200 revolutions per minute; the consumption of steam was 15·86 lbs. per I.H.P. hour. The displacement of the vessel is $44\frac{1}{2}$ tons. These steam turbines are driven by the reaction or impulse of jets of steam which are directed against the moving vanes by alternate rows of fixed vanes. During the passage of the steam through the moving vanes, the peripheral velocity is altered, and the alteration of the peripheral moment of momentum measures the turning moment about the axis of the turbine. The heat energy of the steam may be assumed as transformed into kinetic energy to such a degree that the initial pressure of 200 lbs. is reduced to a pressure $13\frac{1}{2}$ lbs. below atmospheric, at the exhaust. The adiabatic law of expansion may be assumed to determine the wetness at any point of the process. The three turbines are compounded so that the expansion is divided into three distinct stages. It was found necessary to make use of so many as three propellers on each of three shafts, in order to reduce the thrust per unit of blade area and thereby avoid the losses due to "cavitation"[†] of the water in front of the blades.

[*] *Proceedings of Inst. of Naval Architects*, April 8, 1897.

[†] *Proceedings of Inst. of Civil Engineers*, vol. cxxii., "Torpedo Boat Destroyers," by J. I. Thornycroft.

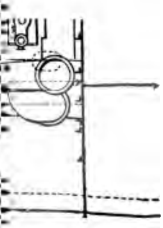
The "Tripoli" of the Italian Navy and the "Kaiserin Augusta" of the German Navy also have triple screws.

General Arrangement of the Machinery.—An example of the plan adopted in the engine-rooms of a twin-screw vessel is shown in the illustrations of H.M.S. "Powerful," which are copied from those given in *Engineering* of October 2, 1896.

In each engine-room there are, in addition to the main engines, the main condenser, with its independent circulating pump on the forward bulkhead (Plate I., Fig. 2); the auxiliary condenser with 1500 square feet of surface, with its air and circulating pump near it (Fig. 2); the hot-well feed pump alongside the feed tank and the hot well, which two receptacles are built into the ship, while a feed filter is placed against the longitudinal bulkhead on an upper platform (Fig. 2). There are three main feed engines on the starting platform (Figs. 1 and 2); two fire and bilge pumps also close to the longitudinal bulkhead (Fig. 2). On the after bulkhead in each engine-room is a two-crank steering engine, so arranged that by means of a friction clutch the one may be disconnected if disabled and the other thrown into gear. The whole of the steering gear is under the protective deck. On the forward bulkhead alongside the three stop valves there is a steam separator (Fig. 2). There is therefore a very extensive collection of machinery in the limited space. The compactness of the arrangement renders every part accessible.

---

* Sir William White (*Proc. Inst. C.E.*, vol. clv., p. 49) states that "the advantage as regards propulsive efficiency is still with twin screws as compared with triple; and that, in spite of the strong advocacy of Admiral Melville, twin screws have been preferred to triple for later American battleships and cruisers up to 25,000 I.H.P. Of course, with three shafts and engines, the manufacturing difficulties are less than with two. This was avowedly the reason why the two American cruisers were built with triple screws." Sir William White continues:—"It is reasonable to suppose that, as higher speeds are attained and larger powers have to be utilised, since the limits of draught of ocean-going steamers are fixed by practical considerations, triple screws may become necessary to efficiency. This anticipation I stated ten years ago, and, in my judgment, that point has been reached, and the use of turbine engines and higher rates of revolution will also render desirable the use of three or four shafts, although the diameter of screws will be made relatively smaller."



In the auxiliary machinery room there is the electric lighting plant. Here are two of Messrs. Allen & Co.'s vertical engines, with cylinders 10 ins. and 17 ins. in diameter by 10-in. stroke, coupled to dynamos which, running at 300 revolutions, develop 600 amperes at 80 volts. There is a third dynamo on the upper deck, the total number of lights being 1000, with six search projectors. There are also four Normandy evaporators. These were illustrated in detail in *Engineering*, vol. lx., p. 12. There are also two distilling condensers and two steam pumps, divided into two complete and independent sets of machinery of equal power, working compound with great economy of boiler steam consumption. Each of the four evaporators may, however, be worked separately when so desired. Automatic feed and steam regulators are fitted so as to prevent the possibility of salting up, and the evaporating surfaces are capable of being easily removed for cleaning. The evaporators are capable of producing from sea water per twenty-four hours the total quantity of 120 tons (26,880 gallons) of fresh water, 25 tons thereof (5600 gallons) being condensed in the distilling condensers for drinking purposes, the remainder in the ship's condensers for boiler feed.

The workshop is on the main deck (Plate I., Fig. 1).

General Arrangement of Auxiliary Machinery.—The modern type of main feed pump with a slow, long, and automatically regulated stroke is so certain in its action that no inconvenience is caused to the boiler attendants when it is placed in the engine-rooms, where it is out of the coal dust. The auxiliary feed pumps are fitted in the stokehold, and, if of the type containing a crank shaft, they require constant adjustment and cleaning, owing to the injurious effect of the dirt and ashes on the working surfaces. It is a great convenience when the dynamo engines are placed in the main engine-rooms where the engineer on watch can supervise them. (In this connection see the chapter on *Merchant Service Routine.*) If fitted in a separate compartment they require independent watch-keepers who, in a small ship, can generally ill be spared from the main machinery.

In the stokeholds, besides the boilers, will be found the auxiliary feed pumps, the fans for supplying air to the fires, the ash-hoist engines, and perhaps an additional ventilating fan; in the case of a Belleville installation, an air-blowing engine also.

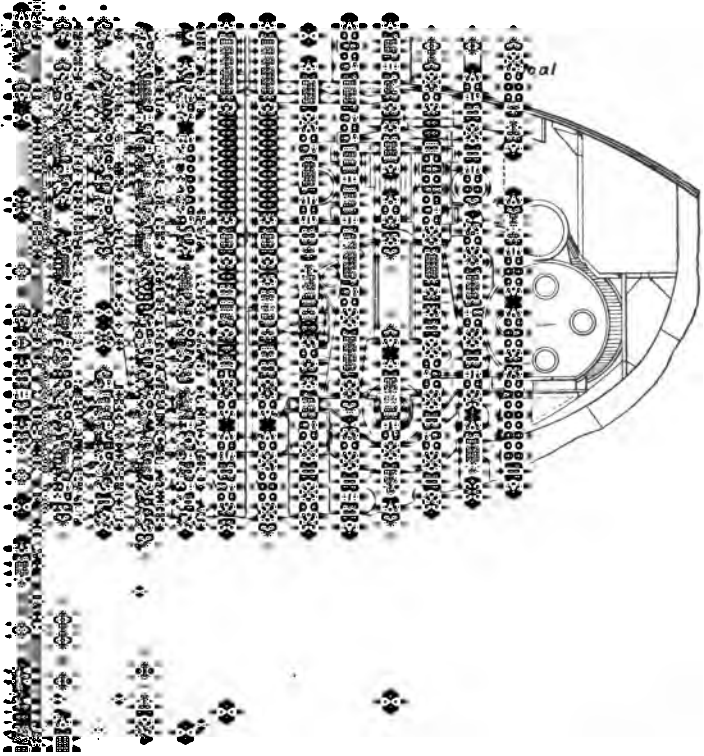
The capstan engine and steering engine are often placed at the ends of the ship, near the capstan and rudder respectively; the Admiralty practice of late is to place the steering engine in the engine-room. The boat-hoist engine and winches are on the upper deck in such a position that the attendants can easily see and obey the signals made by the officer hoisting boats or cargo.

Hydraulic-pumping engines are fitted in large battleships. They are generally in duplicate compartments, forward and aft, situated below the armour deck. The compartments containing the Whitehead torpedoes, air compressors, and dynamos are also located below the armour deck, and are dependent on artificial illumination and ventilation.

Spare Gear.—A considerable quantity of spare gear is carried for main and auxiliary engines; it is generally bolted to the bulkheads in positions as close to the engines as possible. For a list see the chapter on *Adjustments*.

The auxiliary engines will be treated in detail later. The most common type is that of the vertical inverted-cylinder, direct-acting engine. The larger engines are generally compound, and the smaller ones simple engines. The steam is supplied by means of an auxiliary steam pipe connected to one or all of the boilers, and the full boiler pressure may be used or a lower pressure obtained by means of reducing valves, as in the case of steering and capstan engines. The auxiliary engines of a ship are collectively of considerable horse-power, as shown by the estimate in Table I.; unfortunately, they are extremely uneconomical, for two principal reasons: Firstly, the auxiliary steam pipe is long, and, as a consequence, some wet steam is supplied, so that the action of the cylinder sides is intensified; secondly, the simple- or double-expansion engines cannot effect a rate of expansion sufficient to utilise the full boiler pressure. Trials carried out by the United States Navy Department showed that the average power developed by the auxiliary machinery varied from $2\frac{1}{2}$ to $2\frac{3}{4}$ per cent. of the main engines, whilst the coal required was from 12 to 15 per cent. of the total consumption, indicating that about 100 lbs. of steam is required per H.P. hour by the auxiliary machinery.

The exhaust steam from the auxiliary engines of a large ship is generally led to a separate auxiliary condenser. The plan has the great advantage that the vacuum in the main condensers is not affected by air leaks through the auxiliary engine drains, or in the auxiliary exhaust pipes; also that the exhaust steam from the auxiliary engines is condensed and returned to the boilers when the main engines are not in use. In small twin-screw ships the auxiliary exhaust pipe is generally fitted to communicate with either of the main condensers. Observation shows that the vacuum in the main condenser used for the auxiliary steam is reduced by about 2 ins. after every precaution has been taken to prevent air leaks.



The use of **feed heaters** is increasing. They may be called condensers, in which the feed water condenses the exhaust steam from the auxiliary engines and is thereby heated and delivered to the boiler at a high temperature. The results obtained in the s.s. "Inchmona," referred to later (p. 69), show the great advantages to be derived from a combined system of feed heating and steam superheating.

AUXILIARY MACHINERY.

The number of auxiliary engines in a modern ship is considerable, more particularly in large battleships. The following list includes the most important of the auxiliary engines of H.M.S. "Irresistible":—

4 Circulating pumps.
4 Fire and bilge engines.
3 Air blowers for furnaces.
10 Fans for furnace draught.
2 Fans for ventilation.
1 Capstan engine.
2 Steering engines.
4 Air-compressing engines.
2 Hydraulic-pumping engines.
1 Auxiliary hydraulic-pumping engine.
4 Barbette-turning engines.
3 Dynamo engines.
2 Boat-hoist engines.
2 Coal-hoist engines.
2 Hot-well pumps.
5 Ash-hoist engines.
3 Main feed pumps.
3 Auxiliary feed pumps.
2 Auxiliary circulating engines.
2 Auxiliary air pumps.
1 Drain-tank pump.
2 Distiller pumps, &c.
2 Evaporator pumps.
2 Turning engines.
1 Workshop engine.
2 Starting and reversing engines.
2 Refrigerating engines.
4 Hyd. motors for chain rammers.
4 Hyd. motors for ammunition hoists.
4 Hyd. hoists for transporting ammunition.

Also the propelling and auxiliary engines of three steam boats, the machinery of the Whitehead torpedoes, and various motors worked by water pressure and electricity.

The progress of marine engineering with respect to the type of engine and boiler, the boiler pressure, piston speed, and indicated horse-power is related in a most instructive paper read by Sir Albert J. Durston, K.C.B., and Mr. Milton before the Institute of Naval Architects in July, 1897, and the reader is referred to that source for further information. The following three tables have been abstracted as especially interesting.

The gradual increase of the boiler pressure in the naval vessels from 22 lbs. per square inch in H.M.S. "Warrior" completed in 1861, up to the pressure of 220 lbs. in use in the "Quail," can be traced in Table I. A further increase to 300 lbs. per square inch has since been adopted for certain designs, the steam pressure being reduced to 250 lbs. at the engines by means of a reducing valve. The most notable feature in recent Admiralty practice is the successful adoption of water-tube boilers. Those in use at present may be divided into two types[*]:—

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[*] See *The Supplement to the Steam Manual*, p. 20.

I.—Table of some Representative Ships of the British Navy,

Name of Ship.	Date of Trial.	Details of Engines.			Revolutions per Minute.	Piston Speed, Feet per Minute.	Total I.H.P.	Air Pressure in Inches of Water.	Boiler Pressure, Lbs. per Square Inch.
		Type.	Diameter of Cylinders in Inches.	Stroke in Feet and Inches.					
Warrior, . .	October, 1861.	Single screw, jet condensing, simple horizontal, trunk.	2 of 112	4 0	54·2	434	5,436	0	22
Devastation, .	October, 1872.	Twin screw, surface condensing, simple horizontal, trunk.	4 of 80	3 3	76·9	500	6,652	0	30
Inflexible, .	November, 1878.	Twin screw, surface condensing, compound, vertical	2 of 70 4 ,, 90	4 0	73·3	586	8,483	0	61
Sanspareil, .	September, 1888.	Twin screw, surface condensing, triple expansion, vertical,	2 of 43 2 ,, 62 2 ,, 96	4 3	100·7	856	14,483	2	135
Prince George,	September, 1896.	,, ,,	2 of 40 2 ,, 59 2 ,, 88	4 3	101·8	865	12,280	1·25	155
Terrible, . .	January, 1897.	,, ,,	2 of 45 2 ,, 70 4 ,, 76	4 0	112·0	896	25,648	0	260
Ferret, . .	October, 1894.	,, ,,	2 of 19 2 ,, 29 2 ,, 43	1 6	360·1	1080	4,474	4·1	175
Janus, . .	November, 1895.	,, ,,	2 of 18 2 ,, 27½ 2 ,, 42	1 6	367·1	1101	3,789	2·5	210
Desperate, .	September, 1896.	,, ,,	2 of 20 2 ,, 29 4 ,, 30	1 6	397·6	1194	5,796	3·5	215
Quail, . .	January, 1897.	,, ,,	2 of 21 2 ,, 32½ 2 ,, 48	1 6	367·2	1102	6,057	4·8	220
Diadem, . .	January, 1898.	,, ,,	2 of 34 2 ,, 55½ 4 ,, 64	4 0	119·0 107·6	952	17,188 12,776	0 0	300 280
*Kent, . .	December, 1902.	,, ,,	2 of 37 2 ,, 60 4 ,, 69	3 6	141·6	991 2	22,259	0·3	278
*Erne, T.B.D., .	December, 1903.	,, ,,	2 of 20 2 ,, 31 2 ,, 48	1 7½	350·0	1137 5	6,971	2·5	248
*King Edward VII.,	..	,, ,,	2 of 38 2 ,, 60 4 ,, 67	4 0	116·5	932	18,130	0·8 0·55	200
*Sentinel, . .	..	,, ,,	2 of 32·5 2 ,, 52 4 ,, 61	2 6	205·0	1024	17,500	2·73	252

* Added to Table, 1905.

EMBODYING THE ADVANCED PRACTICE AT THE TIME THEY WERE DESIGNED.

Number and Description of Boilers.	No. of Auxiliary Engines.	Approximate I.H.P. of Auxiliary Engines.	(Tons) Weight of				I.H.P. per Ton of			Lbs. of Coal per I.H.P. per Hour.
			Machinery, Boilers, and Water at Working Height.	Main and Auxiliary Engines.	Boilers and Water at Working Height.	Water in Boilers at Working Height.	Engines.	Boilers.	Water in Boilers.	
Rectangular iron, 10 in number.	8	350	898·2	421·6	476 6	171·7	12·97	11·47	31·87	3·75 to 5
Rectangular iron, 8 in number.	16	880	971·9	484·2	487·7	125·8	13·73	13·64	52·87	3·12 to 4 42
Oval, single- and double-ended, 12 in number.	82	1400	1366·4	654·2	712·2	187·38	12·96	11·9	45·27	2·38 to 2·74
Circular, single-ended, steel, 8 in number.	92	2100	1089·4	509·2	581·1	132·0	*28·44 †15·85	24·96 13·87	109 61·14	1·88 to 2·6
Circular, single-ended, steel, 8 in number.	146	2800	1326·6	623·8	702·7	165·2	*19·7 †16·77	17·33 14·89	74·33 63·34	1·82 at 50 °/ₒ of full power.
Belleville, water-tube, 48 in number.	89	2900	2224·8	1076·4	1148·3	48·75	23·8	22·3	526·1	1·71 at 74 °/ₒ
Normand, water-tube, 4 in number.	19	150	123·6	59·4	64·1	11·48	75·2	69·7	389·7	2·3 at 11 knots.
Reed, water-tube, 4 in number.	20	170	120·0	49·0	70·69	7·95	77·3	53·6	477·0	2·5 at 13 k.
Thornycroft, water-tube, 8 in number,	18	230	127·9	61·5	66·46	7·75	94·3	87·2	747·0	2·5 full k. 1·67 low k.
Normand, water-tube, 4 in number,	17	230	144·3	68·6	75·7	11·25	88·4	80·1	539·0	2·64 full k. 1·64 low k.
Belleville, with economisers, 30 in number.	73	1500	1525·0	725·0	800·0	43·0	22·7	20·6	383·0	†1·77 at 20·6 k. 1·59 at 18·8 k.
Belleville, with economisers, 31 in number.	64	1000	1802·5	887·5	915·0	48·0	24·8	24·0	458·0	1·89 full k. 1·83 at 74 °/ₒ 1·8 at 21 °/ₒ
Reed, 4 in number.	25	300	202·0	74·0	128·0	13·8	94·2	54·4	505·0	2·25
Cylindrical. 6 in number. Babcock & Wilcox, 10 in number.	..	2250	1885·0	821·0	1064·0	175·0	30·0	20·2	102·0	..
Normand, 12 in number.	43	1000	885·0	468·0	417·0	44·0	36·3	40·7	387·0	..

* Forced draught power. † "Natural" draught power.

(*a*) "Those with tubes of large diameter, thoroughly accessible both inside and outside for examination and cleaning, and with their internal steam and water passages so large as to render any obstruction to dirt or grease practically impossible. Such boilers are suitable for any vessels in which the maintenance of high power for long periods may be desirable." The full power is obtained from these boilers by what is termed "natural draught," the stokehold fans being used to maintain an air pressure of a small fractional part of an inch. To this type belongs the Belleville boiler.

(*b*) "Those with tubes of small diameter, very light for the power developed, and capable of being used under high forced draught without leakage of tubes or other injury." Such boilers are suitable for vessels in which machinery of torpedo-boat type is necessary. The circulation of the water in type (*b*) is generally much more rapid than in type (*a*), and it is for this reason that the former is capable of working under a comparatively high air pressure.

Various systems of forced or induced draught are fitted to the boilers of ships of the Royal Navy and Merchant Marine, but, broadly speaking, the boiler practice in the Royal Navy is to obtain the maximum power, on occasion, from a given weight of boiler and contained water, whilst in the Mercantile Marine the various systems have generally the economy of coal as their main feature.

In Table I. the I.H.P. of the auxiliary engines was not obtained directly from diagrams, but was estimated from the quantity of steam and coal required by them. In comparison with the measurements made by the U.S. Navy Department, the figures given are high.

The following figures obtained in the U.S. triple-screw cruiser "Columbia" are interesting:—*

I.H.P. of the three main engines, ...	18,000	
,, ,, ,, circulating engines, . .	30	
,, ,, ,, air pumps, ...	57	
,, ,, two auxiliary air and circulating pump engines, ...	4	
,, ,, three fire and water service pumps, .	11·6	
,, ,, three fire and bilge pumps, . . .	22	
,, ,, three fire, feed, and bilge pumps, .	3·5	
,, ,, six main feed pumps, ...	178	
,, ,, two auxiliary feed pumps, . . .	13	(estim^{d}.)
,, ,, sixteen blowing fan engines, . .	154	
,, ,, two auxiliary ,, ,, . . .	12	(estim^{d}.)
,, ,, ,, ,, ,, in engine-rooms,	5	(estim^{d}.)
,, ,, one dynamo engine, ...	28	(estim^{d}.)
Total I.H.P. of auxiliary engines, ...	518	
Total number of steam cylinders in the ship, . .	184	

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* It should be noticed that there is no hydraulic machinery in this ship.

II.—The Cunard Fleet.

Name of Ship.	Description of Engines.	Cylinders.		Boiler Pressure, lbs. per sq. in.	Piston Speed, ft. per min.	I.H.P.	Coal per day in tons.	Coal per I.H.P per hour in lbs.
		Diam.	Stroke.					
1860.		Inches.	Inches.					
Cambria, ...	Side lever,	77½	90	10	256	1040	44	4·0
America, ...	,,	88¾	96	18	224	1600	58	3·38
Niagara, ...								
Europa, ...	,,	90	96	18	224	1850	67½	3·41
Canada, ...								
Asia, ...	,,	96⅝	108	18	261	2160	74	3·2
Africa, ...								
Arabia, ...	,,	103	108	18	270	3000	105	3·2
Persia, ...	,,	100½	120	24	320	4180	157	3·5
Satellite, ...	One cylinder, side lever,	50	42	12	...	...	...	...
Etna, ...	Beam geared,	42	38½	16	218	...	28	...
Delta, ...	,,	76¾	63	14	325	...	50	...
Jura, ...	,,	76	65¼	14	272	1350	48½	3·35
Melita, ...	Oscillating geared,	50¼	54	13	252	612	22¼	3·38
Palestine, ...	,,	57	57	16	237	...	30	...
British Queen, . .	Vortical direct,	48	33	12	330	500	20	3·73
Balbec, ...								
Karnak, . . .								
Stromboli, ...	,,	42·5	31	17	284	...	19	...
Damascus, ...	,,	52	36	14	270	680	27	3·7
Australasian, ...	,,	90	42	20	294	3070	100	3·0

II.—THE CUNARD FLEET (*Continued*).

Name of Ship.	Description of Engines.	Cylinders.		Boiler Pressure, lbs. per sq. in.	Piston Speed, ft. per minute.	I.H.P.	Coal per day in tons.	Coal per I.H.P. per hour in lbs.
		Diam.	Stroke.					
1897.		Inches.	Inches.					
Satellite,	One cylinder, side lever,	50	42	...	...	...	...	...
British Queen,	Compound,	29, 54	36	65	360	580	14	2·25
Marathon,	,,	44, 78	42	66	392	1150	28	2·27
Kedar,	,,	39, 68	45	60	405	850	23·5	2·5
Tarifa,	,,	38, 68	48	70	424	1100	26	2·2
Aleppo,	Triple expansion,	24¼, 35¾, 58½	48	160	536	1250	18	1·34
Samaria,	Compound,	45, 80	42	70	392	1600	39	2·27
Trinidad,	,,	39, 69, 75	45	70	390	900	24	2 5
Saragossa,	,,	40, 71	45	67	405	1000	27	2·5
Cherbourg,	,,	33½, 58½	42	61	357	600	16	2·5
Bothnia, Scythia,	,,	60, 104	54	67	513	3300	76	2·15
Gallia,	,,	64, 80, 80	60	75	550	4500	100	2·07
Catalonia,	,,	51, 88	60	80	610	3000	69	2·14
Cephalonia,	,,	52, 93	66	90	605	4000	87	2·03
Pavonia,	,,	...	...	90	660	...	...	...
Servia,	,,	100, 72, 100	78	85	700	9500	173	1·7
Aurania,	,,	91, 68, 91	72	90	764	9700	180	1·72
Umbria, Etruria,	,,	105, 71, 105	72	110	780	14,500	285	1·83
Campania, Lucania,	Twin screw, triple, five cylinders to each engine,	2 of 37 1 of 79 2 of 98	69	165	805	28,000	...	...
Sylvania, Carinthia,	Twin screw, triple,	22½, 36½, 60	48	180	680	4200	63	1·4
Skirmisher,	Twin screw, compound,	21, 42	32	...	...	...	...	...

Data of Vessels added to the Cunard Fleet between 1897 and 1905.

Name of Ship.	Description of Engines.	Cylinders. Diameter.	Cylinders. Stroke.	Boiler Pressure.	Piston Speed.	I.H.P.
		Inches.	Ft. ins.	Lbs. per sq. in.	Feet per min.	
Caronia,	T.S. Quad. Exp., balanced on the Yarrow-Schlick-Tweedy system,	39, 54½, 77, 110	5 6	210	900	20,000
Carmania,	Turbine (Triple Screw), . .	...	...	190	...	about 20,000
Saxonia,	T.S. Quad. Exp., 4 cylinders, .	29, 41½, 59, 84	4 6	210	720	10,000
Ivernia, .	,,	28½, 41, 58½, 84	4 6	210	720	10,000
Carpathia,	,,	26, 37, 53, 76	4 6	210	750	8,000
Ultonia,	T.S. Triple Exp., 3 cylinders, .	23½, 38½, 68	4 0	200	560	5,000
Slavonia, .	,,	24, 40, 70	4 0	200	640	5,000
Pannonia, .	,,	25½, 42, 70	4 0	190	600	5,000
Brescia, Pavia, . Tyria, . Cypria, Veria, .	S.S. Triple Exp., 3 cylinders, .	24, 40, 66	3 9	200	480	1,800

III.—Particulars of the Fleet of the P. and O. Company.

Date.	1860.	1870.	1880.	1890.	1897.
Number of vessels owned by the company, . . .	39	43	50	51	59
Gross average tonnage, . .	1492	1888	2735	3901	4896
Tonnage of largest vessel, .	2283	3664	4023	6600	8000
Average I.H.P., . . .	1148	1616	2428	3759	4713
Greatest I.H.P., . . .	2189	3300	3800	7000	11,000
Greatest boiler pressure, lbs. per square inch, . .	21	40	80	160	170
Greatest piston speed, feet per minute, . . .	348	468	640	744	894

The first compound engines used by the company were fitted in the s.s. "Mooltan" in 1861, with a boiler pressure of 27½ lbs. The first triple-expansion engines used by the company were fitted in the s.s. "Coromandel" in 1885, with a boiler pressure of 140 lbs.

CHAPTER II.

THE CONDITIONS OF SERVICE OF ENGINEER OFFICERS R.N., AND R.N.R.

THE present chapter is intended as a help to the young engineer who is about to go afloat and take up the duties of his profession; engineers of the R.N.R. may also usefully compare their responsibilities when serving in H.M. ships, with those they undertake in the merchant service.

Duties on Receiving Appointment.—The first duty of the young officer on being appointed to a ship is to acknowledge the receipt of his appointment as directed on the appointment. This is done in a few words on a sheet of foolscap thus:—

Address,
Date,

SIR,
I have the honour to acknowledge the receipt of my appointment to H.M.S. "   ," and I have the honour to remain,
SIR,
Your obedient servant,

To
THE SECRETARY OF THE ADMIRALTY
(*Or as directed in the appointment*).

In "service" letters one-quarter of the page is left as a margin at the top and down the left-hand side.

Expenses.—A sum of one shilling a day is paid by an assistant engineer to the messman, to whom the Admiralty make a further allowance; the total expenses of living in a gun-room are from £2 to about £4 a month, according to the officer's means. The senior members of a gun-room mess are expected, by influence and example, to support the sub-lieutenant president in maintaining an orderly and well-arranged mess. The amounts expended by a gun-room officer in extras and wine are subjected to control. The regulations respecting wine are stringent. On promotion, after about five years' service, the engineer joins the ward-room mess to which all the senior officers belong—except, of course, the captain. All ward-room officers generally obtain cabins, except the juniors in a flag ship.

Necessary Clothing.—In addition to the uniform prescribed it is necessary to provide various articles of clothing. A suit of canvas overalls to wear when crawling in bilges may be recommended. Until a proper acquaintance with the feed pipes and other fittings usually hidden under the plates, and also of the interior of cylinders and boilers, is acquired, there will be a good deal of crawling about to be done, and the chief engineer will expect to see proper efforts made to acquire this information; consequently, one must be possessed of a suit of overalls on joining the ship. The Admiralty issue 12 yards of coarse duck, for the use of each engineer, every year, and this material is used for the purpose of making overall suits. Since the engine-rooms of H.M. ships have usually a temperature of about 100° F., the most comfortable shirt on watch will probably prove to be a thin flannelette, which can be often washed without shrinking. Shoes for the engine-room should have very thick soles; otherwise a four-hour watch on the hot plates will make the feet tender. Shoes are recommended in preference to boots, to render the inevitable change on leaving the engine-room department easier. The deck officers very naturally resent the dirty marks made on the decks by boots worn in the engine-room, and the only thorough prevention is to change on leaving the department. White cashmere neck wraps will be found very useful to put on if duty suddenly calls you on deck. They look neat, and will be found indispensable for coaling ship. Socks should be of the strongest as it is difficult to get them darned at sea. Sea boots are not a necessity to the engineer, but they will be found useful when coaling ship. It should be noted that white uniform can be bought cheaper at Hong Kong, Bombay, and Malta than at home, especially at the two former places; though the quality is not quite so good, this course is to be recommended. As regards private clothes, the young officer will not find stowage for many suits. A blue serge suit is generally useful, and a Norfolk jacket suit is best for a ramble on shore. An overcoat is a necessity to guard against chills on returning in the evening boat. Room can generally be found for a cricket bag or for a rod and gun. Only essential books should be taken; they have to resist rough treatment from cockroaches, packing, and, occasionally, from sea water. Castor oil is said to protect the bindings from cockroaches. Books should be packed separately and surrounded by soft clothing. A good set of drawing instruments should be provided. Sketch books are a necessity for both rough and finished sketches; they should have strong bindings. The author recommends the young engineer to invariably carry a pocket book in which to note down defects in the machinery as observed. The most urgent can then be picked out when an opportunity occurs to set them right. All orders received should also be immediately committed to writing for future reference when carrying them out, or for transmission to others. Especially is this important when carrying out watch-keeping duties. It will be found a very useful practice to make notes and sketches of any interesting repairs which may be carried out; in time a valuable set of sketches may thus be accumulated. Figured dimensions should be marked on such sketches. In addition, an engineer should possess a sketch book devoted to the leading features of the ship he is serving in, as detailed later.

Duties of Engineer Officers.—These duties are laid down in the *King's Regulations and Admiralty Instructions*, of which it is ordered that every officer must possess a copy. The book is produced when the admiral in command of a fleet makes his periodical inspection. In addition, the *Steam Manual* is written for the instruction of engineer officers and engine-room artificers, and an intimate acquaintance with its contents is indispensable. Copies are obtained on application from the office of the senior engineer officer in the Steam Reserve and also from the paymaster of a ship before leaving the home port. Every engineer officer and engine-room artificer is entitled to a copy, to be considered as his personal property (*Steam Manual*, Art. 2). The *Steam Manual* may be quoted in this book by the initials *S.M.*

Discipline.—Article 149 of the *Steam Manual* is very important and is here quoted:—"During the absence from the ship of the chief engineer the senior engineer officer remaining on board is to observe and follow the instructions for that officer, and to be responsible for the care and proper working of the machinery and all parts connected therewith."

Properly understood, this paragraph directs the discipline to be carried out in the department. The young officer must take care to make the proper reports as to the progress of work and on other matters to his chief, in order that the latter may be in possession of the fullest information as to the state of his department. Should the chief not be on board the reports must be made to the senior engineer left in charge. It must not be supposed that reports are made to the chief engineer simply as a compliment to his rank.

Acquaintance with General Run of Ship.—As soon as possible after joining the ship the assistant engineer should endeavour to become familiar with the general run of the ship. He should trace the run of the steam and exhaust pipes, making sketches showing the bulkheads passed and all communicating valves on the main and auxiliary steam pipes. His task will be made easier by the use of existing sketches, which he should copy and use to verify his own. He should note carefully the method of shutting off certain sections of pipe, and consider the possibilities of alternate routes for the steam. Equally important is the lead of feed pipes and the delivery of each separate feed pump. It is necessary to know accurately the function of each pump, and for what boilers it may be used, either in ordinary practice or on an emergency. The same course of study must be applied to the voice pipe leads, the lead of the fire main, the ventilation trunks, the water-tight doors and drain valves, and to the flooding arrangements. The water-tight bulkheads of a ship are lettered, and also bear the number corresponding to the framing of the ship. It is important to represent the bulkheads in their place on all sketches made, and to insert the number and letter corresponding to them. By this means a knowledge of the relative positions of compartments on different decks will be acquired.

It is only after an engineer is intimately acquainted with his department that he is able to take prompt action in any great or small emergency which may arise. At such a time he should feel no necessity to wait and seek out a particular subordinate who has a more detailed knowledge of the part affected. The confidence and authority this knowledge will give him are invaluable.

Steaming Watches.—It may be useful to state here that the watches on board are divided up as follows :—

Midnight	to	4 a.m.,	called the	"middle watch."
4 a.m.	,,	8 a.m.,	,,	"morning watch."
8 a.m.	,,	noon,	,,	"forenoon."
Noon	,,	4 p.m.,	,,	"afternoon."
4 p.m.	,,	6 p.m.,	,,	"first dog."
6 p.m.	,,	8 p.m.,	,,	"second dog."
8 p.m.	,,	midnight,	,,	"first watch."

On first joining, the assistant engineer is placed in a watch with an experienced officer until judged familiar with his duties, whereupon he is placed in charge, generally after some months of instruction in his duties.

The Admiralty instructions direct that every engineer, except the chief, is to be employed on watch from four to eight hours out of the twenty-four.

The most arduous watch keeping duty experienced under ordinary conditions is that known as "three watches." In such an arrangement an officer keeps every third watch in rotation. In addition, an assistant engineer attends the ordinary drills at his proper station; the most important being "general quarters," "fire quarters," "collision quarters," and "man and arm ship." The watch bill made out on board will contain all the information necessary for the carrying out of these drills.

Sub-charge, of Auxiliary Machinery.—The various sub-departments under the chief engineer comprise—(1) The hydraulic machinery; (2) the dynamo machinery and torpedoes; (3) the double-bottom compartments, the water-tight doors, the ventilating, pumping, and flooding systems, and some miscellaneous engines, such as the capstan engine and boat hoist. This division is general but not universal.

In large ships after the young engineer has acquired the general knowledge alluded to in an earlier part of this chapter, he will generally be associated with one particular department, first to become acquainted with the particular duties of the department, and afterwards to see them properly carried out. At the same time he will take "day's duty" in turn with the other junior engineers, when his duties, as detailed later, are more general. One junior engineer may be partly employed, for a period of some months, to assist the chief engineer with the clerical work of the department; this work consists of the store accounts, and the writing up of the engine-room registers, and other reports ordered by the regulations. The knowledge so acquired is necessary later when the officer is placed in charge of the machinery of a small ship.

The assistant engineers are responsible to the chief engineer for the efficient condition of their department, as laid down in the *Steam Manual*, Article 142. They will also receive more or less assistance and supervision from the senior engineer in his capacity of general assistant to the chief.

In small ships the duties are more general, because there are not so many departments. Thus, hydraulic machinery is not fitted, and there are no submerged torpedo tubes; neither is there the same number of auxiliary engines outside the engine-room proper. The chief engineer will generally do all the clerical work himself, and when he has only one or two assistants the junior must be prepared to undertake a more varied duty than is usual in large ships.

An engineer in the Royal Navy is not generally required to do actual manual labour, but he should remember that the necessity may arise, and should provide himself with practice when convenient opportunities arise. In the author's opinion the skill possessed by a clever mechanic is as much deserving of practice as any other hard won accomplishment, and from this point of view the assistant engineer should take every opportunity of exercising himself in the use of tools.

Charge of Men's Clothing.—It is now usual for the engineer officers to be held responsible for the dress and general appearance of the stokers. The usual arrangement in a large ship is that each of the junior engineers has charge of a subdivision of the stokers, and the senior engineer helps each to carry out the duties required by the various inspections ordered. Generally speaking, the whole kit and bedding of each man must be mustered and inspected once in each three months. On Sunday mornings, and twice each week day—at morning divisions and evening quarters—the men are inspected in the "rig of the day." When the ship is in harbour most of the stokers are at work when "divisions," and often also when "evening quarters," are sounded off; those who are free to attend are inspected. At sea all the stokers, not on watch or on day duty, attend these inspections. Since the opportunities at other times are few, it is especially important to carefully inspect the stokers' dress on Sunday morning.

As these duties are somewhat strange to engineers it will perhaps be useful to point out that the smallest irregularity ot dress, such as a dirty mark, a discoloured button, or a badly tied tape, will not escape the captain's eye when he subsequently inspects the men; some matters may be put right at the time of inspection, but for others it is necessary to report the matter to the officer in charge of the division, who will probably order the man to present himself for inspection at a future stated time, or direct him to furnish himself with a new garment fit for inspection. It will be necessary to acquire, and as soon as possible to become acquainted with, the separately printed regulations as to uniform.

SPECIMEN OF ORDERS FOR "DAY'S DUTY" IN HARBOUR.

The junior engineers will keep "day's duty" in rotation.

The E.O. of the day will see all hands mustered, properly dressed, and that they turn to at the time directed. The chief stokers of the various departments will report to the E.O. of the day when the hands have turned to. The E.O. of the day will report any absentees to the senior engineer. He will muster those stokers who attend "evening quarters," inspect them, and report to the executive officer taking "evening quarters."

He will see that the rough engine-room register is written up with all information concerning the machinery at work.

He will be responsible for any special duty outside working hours. If the ship's steam boats are running he will report to the senior engineer whether the boat is likely to be employed for more than a period of twelve hours, in order that a relief crew may be told off.

The E.O. of the day will go the "rounds" at night as directed in the *Steam Manual*, Art. 150; he will be accompanied by the engine-room artificer and chief stoker of the day, and he will meet and report to the commander at an appointed place during the latter's "rounds;" he must also report the result of this inspection to the chief engineer.

He will go the rounds of the department at least once in each night watch, out of working hours, and will initial the register to certify that he found the department as reported therein. Any unusual circumstance must be immediately reported to the senior and chief engineers.

He will see that the fire-engines are ready for pumping water to wash decks at the time ordered in the morning watch. He will see that the main drain and bilges are pumped out at the times directed.

He will see the department properly cleared up after working hours, and will receive the storekeeper's report that all lamps and tools are returned to the store; he will also see that all spanners are replaced in their proper racks.

The quantity of water in the reserve feed tanks is to be ascertained by the E.O. of the day in the morning watch, and is to be noted by him in the E.R. register.

During his rounds the E.O. of the day is to take special notice of the steam pressure, feed pumps, feed water supply, boiler gauge glasses, and the density in the boilers; and he will also see that the evaporators are working under the conditions ordered. Any sudden rise in density of the boilers is to be immediately reported to the senior engineer.

He will also see that the lubricators of machinery in use have been properly attended to, and that the bearings are running cool.

He is responsible that the ventilating fans are run as directed.

He must be present to personally supervise any change ordered with respect to the machinery at work for auxiliary purposes, such, for instance, as a change of the boilers in use,

CHAPTER III.

ENTRY AND CONDITIONS OF SERVICE OF ENGINEERS IN THE LEADING STEAMSHIP LINES.

Entry of Engineers.—The engineers are generally selected from applicants, over twenty-one and under twenty-seven years of age, who have served an apprenticeship of not less than five years, preferably in a marine engineering establishment. It is in their favour if they have also worked for two or three years as journeymen. Successful candidates are often indebted to their associations or to influential personal recommendations. In every case the candidate has to satisfactorily undergo the ordeal of a personal interview with the superintending engineer, when the latter forms an opinion of the candidate's bearing, general education, and intelligence. A good physique is essential; in some "lines" a standard of height and chest measurement has been fixed, and candidates must also submit themselves to a medical examination. A technical college education is not essential, but a candidate should have a sound general education and should show intelligence. If he has attended the evening classes of a good technical college, and can produce certificates for such work, he will probably be able to satisfy the educational standard. The superintending engineer of leading steamship companies attach much importance to the practical ability of candidates, and take pains to explain that their engineers must be first-class workmen rather than merely qualified to act as draughtsmen.

A selected candidate is employed for some months on the company's shore staff, either in the shops or on board steamers, and assists with the current repair and overhaul work; during this time he receives a rate of pay depending on his trade. A probationer is not allowed to close valve chests, cocks, or other fittings before his work has been inspected by one of the senior engineers of the ship's staff, whose duty it is to see that all is in order before parts which have been overhauled are closed up. During the time of service on the shore staff the candidate is kept under the observation of the superintending engineer and of his assistants, and reports are made from time to time; if the conduct or ability of the candidate is not satisfactory, he is not retained in the service. Strict sobriety is essential.

When a vacancy occurs in a ship's complement it is filled by the senior man on the shore staff, who then takes rank as an engineer officer of the company, usually in the lowest grade, say seventh or eighth engineer. It may be here pointed out that the would-be sea-going engineer should try and gain acquaintance with the necessary discipline of a ship; in particular as to his relation with the chief and second engineers, who are responsible for the routine and work carried out in the department. He should also learn how to deal with greasers and firemen, who are not always too careful in executing the orders given by junior engineers. He should learn his position as part of the ship's company and become familiar with the relations existing between himself and the officer of the watch, and also with the captain's authority. A few enquiries, and a habit of observation exercised during the time he is temporarily employed on overhaul work, may enable the young engineer to take up his position naturally and satisfactorily when he joins a ship's staff.

The working hours in the factories are, as a rule, from 7 a.m. till 5.30 p.m. or thereabouts, and on Saturdays the works close at 1 p.m. Whilst employed on the shore staff the probationer is encouraged to attend evening classes on applied mechanics, steam, mechanical drawing, &c., at the various technical colleges. Although no definite educational examination is held for the entry of junior engineers into the Merchant Service, yet it is impossible to secure promotion above the grade of fourth engineer until the necessary Board of Trade certificates are obtained. It is quite usual for the fourth engineer to hold a second class, and the third engineer a first-class Board of Trade certificate; and very often the second, third, and fourth engineers of a "liner" all hold a first-class certificate. A junior engineer must usually serve several years in a "liner" before obtaining the position of fourth, which gives him charge of a watch. For this reason many young engineers start their sea-going life in a cargo steamer, where they get charge of a watch much earlier, and can then count their sea time and qualify for the Board of Trade certificate. Often, however, the training and discipline there experienced is inferior to that obtained on board a "liner."

The regulations regarding Board of Trade certificates for engineers will be found in the Appendix. With regard to the examinations, the following books will be found to contain much valuable information:—Bergen's *Marine Engineer;* Davies' *Solutions to First-Class Questions;* Reed's *Engineer's Hand-Book to the Board of Trade Examinations*, and the *Guide-Book for Extra First-Class Certificates* by the same author. See also Constantine's *Marine Engineers: their Qualifications and Duties.*

The following tables give an example of the number and composition of the engineering staff of a "liner":—

WHEN FIREMEN AND TRIMMERS ARE "NATIVES."

Steamers.	Storekeeper, Lampman, Cook, Messroom Steward.	Engineers, including Chief Engineer and Boilermakers.	Total Number Greasers.	Total Number Firemen.	Total Number Trimmers.	I.H.P.	Coal per I.H.P. consumed per hour.	Coal Worked in Tons per hour.	
								Per Fireman.	Per Trimmer.*
S.S. "A,"	5	9	8	53	37	11,000	1·5	0·417	0·597
1 electrician, 2 refrigerator engineers, 1 hydraulic winchman.						cylinders—42¼″, 68″, 74½″, and 74½″.			
S.S. "B,"	4	7	4	29	20	6,000	1·5	0·414	0·6
1 electrician, 1 refrigerator winchman, 1 winchman.						cylinders—38″, 59½″, and 96″.			
S.S. "C,"	4	7	5	27	18	4,500	1·7	0·378	0·567
1 electrician, 1 refrigerator winchman, 1 winchman.						cylinders—53″ and 101″.			

The men are employed in "three watches."

ENGINE-ROOM STAFFS (EUROPEAN).

Minimum Staff.

2 engineers, 5 firemen, and 1 donkeyman.

100 to 200 N.H.P.

4 engineers, 1 storekeeper, 1 donkeyman, and 1 fireman per 18 ft. fire grate.

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* If coal is handled twice by trimmers, this column of figures is doubled.

200 to 300 N.H.P.

4 engineers, 1 storekeeper, 1 donkeyman, 2 greasers, and 1 fireman as above.

300 to 400 N.H.P.

5 engineers, 1 storekeeper, 1 donkeyman, 2 greasers, and 1 fireman as above.

400 to 600 N.H.P

6 engineers, 1 storekeeper, 1 donkeyman, 3 greasers, and 1 fireman as above.

600 N.H.P. and over.

7 engineers, 1 storekeeper, 1 donkeyman, 4 greasers, and 1 fireman as above.

Storekeepers, donkeymen, greasers, and firemen may be placed on the Articles as firemen, trimmers, &c.

The N.H.P. to be found in all cases by the following rules:—

Simple Condensing Engines.

D = diameter of cylinders in inches.
N = number of cylinders.

Rule 1.— $$\frac{D^2 \times N}{30} = \text{N.H.P.}$$

Compound Condensing Engines.

Rule 2.— D = diameter of low-pressure cylinder in inches.
d = ,, high- ,, ,,
N = number of low-pressure cylinders.
n = ,, high- ,,

$$\frac{(D^2 \times N) + (d^2 \times n)}{30} = \text{N.H.P.}$$

As to fire grate, divide the total fire-grate surface of all the main boilers by 18. If the quotient contains a fraction equal to one-half or upwards, then the next higher whole number will represent the number of firemen.

The assumption is that 16 lbs. of coal is consumed per foot of grate surface per hour.

EXAMPLES OF ACTUAL STAFFS (EUROPEAN).

Steamers.	Engineers, including Chief Engineer and Boilermakers.	Greasers.	Firemen.	Trimmers.	I.H.P.	Coal Consumed per I.H.P. per hour.	Coal Worked in Tons per hour.	
							Per Fireman.	Per Trimmer.
						lbs.		
S.S. "A,"	10	9	24	15	8500	1·5	0·71	1·14
S.S. "B,"	8	9	18	12	6500	1·5	0·725	1·0875
S.S. "C,"	6	6	12	9	4400	1·48	0·729	0·975

A large Liner carries a chief engineer, second, third, and fourth, engineers, and also from two to six assistant engineers employed on watchkeeping duties. The junior engineers are distributed over the three watches under the second, third, and fourth engineers, and they are generally employed on stokehold duties. In the stokehold they must superintend and direct the working of the boilers, and must attend personally to the distribution of the feed water and maintain a uniform system of stoking and cleaning fires. Considerable personal influence over the firemen is often required to induce them to keep the fires in proper condition.

The following points are found to require the constant attention of the engineer:—The back bars must be kept covered; the bridge and furnace door dead plate kept clear of fire. In double-ended boilers the doors of opposite furnaces must not be opened at the same time, particularly when working with forced draught. The fires must be cleaned with as little delay as possible, and the ashes heaped in suitable places.

It is no uncommon thing for the engineer to relieve a fireman and show him how his work should be done. Generally speaking, there is no intermediate grade between the engineer and the men working on the fires, so that the various duties of a stokehold watch carried out by the chief stoker or E.R. artificer of the R.N., fall on the junior engineer. On the other hand, the system of automatic regulation of pumps is very general in large ships, and the engineer is not compelled to devote much time to their working, but can concentrate his attention on the boilers. Fans are generally employed to supply air to the boilers under various systems of closed or open stokeholds and ashpits. It is not generally necessary to sweep tubes during the watches, as the soot can be blown away by the fans. Ashes are put overboard by the firemen; the ash shoots being led through the gratings over the boiler rooms to the upper deck, and serving as downtakes for air when not in use. There is a very convenient form of ash ejector known as "See's," by means of which ashes put into a receptacle on the stokehold plates are ejected overboard through an inclined rising tube, by a jet of water at high pressure supplied by a duplex pump. By this means the ashes are blown out 20 feet clear of the ship's side and above the water line.

The duties of the engineer in charge of a watch are sufficiently various. In addition to the main engines the following auxiliary machinery is generally to be found in the engine-room and requires supervision:—The sanitation, main feed, and bilge pumps at the back of the main engines and worked by a rocking lever; the duplex main feed pumps controlled by automatic float gear; the feed-water filters and heater; the evaporators and distillers for making fresh water; an auxiliary condenser for dealing with the exhaust steam of the auxiliary engines; various ventilating fans; the main circulating engines and pumps in duplicate; the electric light engines—two or three sets in number—each capable of generating about 220 ampères at 105 volts; the refrigerating machines for freezing the cargo or the ship's provisions, a large or a small machine, and sometimes the two together; the hydraulic pumping engine for supplying water under pressure to the cranes, capstan, and bollards; and a small air compressor to charge the reservoirs of the hydraulic system.

Suitable instructions compiled for several types of these auxiliary engines will be found in the chapter on *Auxiliary Machinery*, together with illustrations; and various special forms of duplex pumps are illustrated in a later chapter. As regards the main engines, see the chapter on *Steaming Routine.*

It will be seen, by comparing the above list of auxiliary machinery with that fitted in a battleship, that the types of engines in the latter are, for the most part, carried in a large liner. The system of hydraulics, for instance, is not so extensive in the liner, but it is represented; and the working pressure is equally high (about 1200 lbs. per square inch) and is led throughout the ship, forward and aft. Again, the engineer who has had charge of a small air-compressing plant will have no new problem presented to him by a larger example of the same type. The engineers of H.M. Navy may not generally be acquainted with the extent of the responsibilities of those serving in "liners;" in reality, the nature of the duties in mail steamships very closely corresponds with those in the naval vessels; and it may be anticipated that the R.N.R. engineers transferred to a battleship will speedily be at home after a short course of instruction in the construction of torpedoes and the special features of hydraulic gun mountings, &c.

As regards accommodation, the chief engineer and second engineers are provided with separate cabins, and the junior engineers generally share cabins, two in each. A bath-room is provided for the exclusive use of the engineers. The chief engineer usually messes in the first saloon, and the remaining engineers have their own mess.

Additional Engineers, &c.—The various auxiliary engines receive the special attention of the engineers carried for the purpose. Some large ships carry the following additional mechanics:—The electrician, the hydraulic engineer, and one or two refrigerating engineers.

These engineers have the same privileges as the assistants for watchkeeping duties; they are sometimes replaced by a class of men called "winchmen," who are promoted to special duties on account of the ability shown by them when serving as firemen. The winchmen correspond closely to the rating of chief stoker in the navy, but sometimes receive much higher rates of pay. They are entrusted with the care of various auxiliary machinery, but are not qualified mechanics who have served an apprenticeship. They are employed on particular duties, and do not take watches in the engine-room or stokehold, nor are they promoted to the rank of engineer.

A boilermaker is also sometimes carried, and occupies the same position as an assistant engineer; he keeps watch in the stokehold. Modern boilers require so few repairs, away from the home port, that the boilermaker is often dispensed with, but he is still useful as a smith if there is no boiler work proper.

Conditions of Steaming.—The routine of vessels employed in the well-known lines is very different to that of the Royal Navy. A liner steams almost continuously at full speed; stopping for a period of a few hours to coal at ports of call, she steams to her destination, where she may stay from ten to fourteen days. On her return to the home port, after an interval of from one to five weeks, she starts on another voyage. Consequently there is very little time or opportunity for repairs to be made between the terminal ports. Generally the repairs at intermediate ports are limited to packing glands and making joints on the smaller steam pipes. There is no regular period for a general refit, although during the annual opening out of machinery for the Board of Trade survey, which is necessary in order to obtain the passenger certificate, the opportunity is taken to make good defects as far as possible. The bearings of the main engines generally run satisfactorily, without adjustment, throughout a distance of 12,000 odd miles under steam.

As regards the auxiliary machinery, the refrigerating machine for the cargo is often required on the homeward voyage only, and can be overhauled by the refrigerating engineer on the outward trip. If only one refrigerating machine is carried for both the cargo and the ship's provisions, the heavy repairs must be done at the terminal ports. A special log for the refrigerating machinery is kept, and contains an account of the time and particulars of work and the stores expended. It is placed in the chief engineer's cabin once or twice a day, and, at the end of the return voyage, is sent to the superintending engineer's office, with the log of the main engines, for inspection.

The hydraulic cranes and bollards are chiefly used in port, and are run by the hydraulic engineer, or winchman, under the supervision and directions of the chief engineer; a log is kept for reporting the stores expended and the time the machinery was in use.

The survey ordered by the Board of Trade includes the following points:—Registered H.P.; names and certificates of engineers; engine-room staff; condition of steering gear and description of steering engine, &c.; particulars of fire hose and steam whistle; general condition of hull and bottom, date of last repair and inspection; particulars of means for closing bunkers; particulars of bulkheads; condition of propeller and shafting, date of last examination; condition of under-water fittings; is stern tube in a W.-T. compartment? is the vessel fitted with water-ballast tanks? is there a pump for each hold, and general particulars and conditions of pumps, main and independent? maker of engines, when built, description, diameter of cylinders and length of stroke; maker of boilers, when made, numbers, description, date of hydraulic test, test pressure, date of last internal examination, particulars of superheating apparatus; when were the boilers last out of the ship? working pressure, dimensions, number of furnaces in each, description of furnaces, condition of shells, furnaces, combustion box plates, end plates, tube plates, all stays and tubes, date of last repair, nature and extent of repairs, by whom made, if tested by hydraulic pressure after repairs, if test was satisfactory; description of safety valves, number to each boiler, diameter, how weighted, load per square inch, diameter of coils and of steel spring, number of coils, condition of valves and springs, levers and pins, if fitted to prevent the pressure being increased when steam is up, and how, description of easing gear and where worked from; stop valves, number on each boiler, how placed, diameter; steam pipes, diameter of main steam pipes, date when tested by hydraulic pressure, pressure to which tested; number and description of steam gauges; number and description of vacuum gauges.

The Routine in the P. and O. Service.—The following outline sketch of this routine is given as an example of the general conditions under which a mail steamer is worked. The longest voyage is from London to Sydney,* and is about 12.500 miles. A ship employed on this service generally makes three trips a year or a total distance of 37,500 miles. The principal ports of call and the lengths of stoppages are as follows:—Gibraltar; Malta, 8 hours; Brindisi, 14 hours; Port Said, 3 hours; Aden, 6 to 12 hours; Colombo, 18 to 24 hours; King George's Sound, 6 to 8 hours; Adelaide, 12 hours; Melbourne, 36 hours; Sydney, nearly a fortnight.

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* The ships of some lines run from England *via* the Cape to Australia without stopping at any port of call.

The tubes of the boilers are swept as far as possible, and all fires are cleaned at each port of call. This requires considerable management as steam is required for working the cargo, and it is not advisable to light up the auxiliary boiler for short stoppages.

The ship is docked, after each return journey, in the Albert Docks in London, during her stay of from two to five weeks. The boilers are opened out, scraped, cleaned, and the zincs overhauled at each terminal port; and, at the same time, the tubes are swept and the soot is cleared out of the uptakes and smokeboxes. A general examination is made on the completion of a return voyage, the shafting being stripped from end to end; and all the journals, including those of the connecting-rod, are examined. At the same time, the cylinders, pistons, and pumps are opened out and examined, packing is renewed where necessary, and leaky steam-joints are re-made.

The bearings very seldom need attention at the ports of call, and will generally run throughout one, or even two, voyages without requiring a re-adjustment.

A period of from fifteen to twenty-four hours is allowed to raise steam. Some of the boilers are very large, reaching a diameter of 18 ft., and they are often double-ended.

Fires are cleaned and clinkered when steaming, as found necessary by the chief; generally not less than once in twenty-four hours. The method employed is to turn the fire on one half the width of the grate over on to the other half; the clinker is then cleared out and all the fire turned over on to the clean side, whereupon the remaining clinker is withdrawn. It is not found necessary to sweep the tubes of boilers when under way, all that is done being to sweep the soot out of the smokeboxes, through the sliding doors in the smokebox bottoms.

Fresh water is taken from shore whenever possible. The storage for ship's use is as much as 110 tons in some cases. There is no considerable reserve of fresh water for the boilers, and sea water is sometimes used, though the general practice is to supply fresh water "make up" from the evaporator.

The list of spare gear carried is quite as extensive as in the R.N. vessels, and includes a spare length of tail shafting and a crank shaft that will fit either the high-, int.-, or low-pressure engine.

Refitting.—The manual work of refitting is apportioned as follows:—The second engineer arranges and generally superintends the work to be done, he also musters and controls the men, and completes the stores up to the allowance. The third engineer examines the pistons, cylinders, and slide valves. The fourth engineer opens out all shaft and connecting-rod bearings. The pumps at the back of the engines and the auxiliary machinery are overhauled by the assistant engineers, who are under the more direct supervision of the second; the latter would generally see all the "leads" taken from these bearings.

(In a good many steamship lines the harbour work is apportioned differently:—The second engineer examines and opens out the cylinders, pistons, and slide valves. The third opens out and examines all journals. The fourth overhauls the air pumps and the other pumps at the back of the engines. The assistant engineers overhaul and examine the auxiliary machinery.)

During the annual survey, assistance is given to the ship's staff by probationers on the sea staff and engineers from the factory; more especially to carry out the examination of the auxiliary machinery, and also, when the ship is dry docked, to carry out the examination and refit of the underwater fittings, valves, and kingstons.

Composition of Watches.—When steaming, the number of men in the engine-room of one of the larger ships is—besides the engineer—two greasers, the senior on the bearings, and the less experienced man on the middle platform to look after the guides, link gear, and rod glands; one greaser on the electric light machinery, one on the refrigerating machine, one on the hydraulic-pumping engine, and one on the fans supplying air to the boilers under Howden's system of forced draught.

Composition of "Native" Staff.—In the P. and O. service these greasers and the firemen are all "natives." In the stokehold there is a chief fireman or "serang," and three leading firemen called "tindels," one for each watch. The "serang" keeps no regular watch in the large ships, but in the smaller ships the "serang" and two "tindels" keep the three watches and assist the junior engineer of the watch. The engineer directs the "tindel" to alter the check valves if the water levels are not kept properly; to avoid confusion the actual adjustment is always performed by one man. In addition to these headmen there is also a coal trimmer "serang," who is usually from Zanzibar. The two "serangs" go on watch with the second engineer. The "tindel" has nothing to do with the feed pumps, which are managed entirely by the engineer.

The winchmen employed on the auxiliary machinery are entered as such, and are always Europeans.

CHAPTER IV.

PROCEDURE FOR RAISING STEAM.*

On the Day Previous.

Boiler-rooms.—Take the dampers down from the uptakes of the boilers to be used, or open them if they be fixed in hinges; open the dampers in the funnels to be used, and take off the funnel covers. Examine the fire bars, renew them if necessary, and see them properly spaced. If the ship is to be steamed at full power, there should be greater air space between the bars, an object effected by removing two or more bars and widening the intervals. The wing bars should always be close to the furnace side, to prevent overheating of the sides. In the case of corrugated furnaces a special pattern of bars is carried, the bar being moulded to fit in the corrugations. The air spaces at the sides may, with advantage, be less than in the centre of the grate. Examine the brickwork of the bridges, &c., and make good any defects. Ascertain that the proper opening for the passage of the hot gases is left in the furnace throat, should the bridges have been repaired. This space is about one-fifth the grate area. Prime the fires; run, or pump, the water level to about half-glass in each boiler. Clean the water-gauge glasses, if dirty, and see that they are properly packed, and that the cocks are free. If the test cocks on the boilers appear partially choked, withdraw the screws fitted for the purpose, and clear the cocks by poking wires through the bore.

Try the feed pumps, by the auxiliary steam, if possible, and work all suction and delivery cocks.

Try the steering engine and gear under auxiliary steam, if practicable.

Oil the bearings of fan engines, and give them a run.

See that the necessary fire irons and shovels are provided and are efficient.

Examine the tops of the boilers and see that nothing inflammable has been left there by the workmen.

Air the coal bunkers to be used, by opening the doors and taking off the lids on deck.

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* The author desires to acknowledge his indebtedness to Engineer Commander F. T. George for the form of the routines given.

To Prime the Fires.—Remove the fine, dusty coal, which always runs out when a bunker is first opened after coaling. This coal can be burnt, at convenience, later, but is not suitable for priming fires. Fires should be primed with small lumps of coal from a bunker which has been in use.

This task is performed by spreading lumps, about 3 to 6 ins. cube, uniformly over the bars. In the furnace mouth coal and broken firewood is piled nearly up to the furnace top, and to light up it is only necessary to place a few shovelfuls of live coals next to the firewood, or the firewood may be dispensed with if a more plentiful supply of live coal is at hand.

See that no loose gear has been left about which would carry away in a seaway. Everything should be properly secured.

Trim all the oil lamps for lighting the gauges, those for use in the coal bunkers, and those on the bulkheads. Clean the globes of electric light lamps, if fitted.

See that the hose required for damping the ashes are rigged in place, and that there is an iron pail in each stokehold for the same purpose.

See that the necessary coal buckets and fire irons are uniformly distributed.

If possible, work all the boiler mountings, but particularly the safety and stop valves, to ensure that none are seized in place.

Open the air cocks on the boilers.

If the ship is at the jetty, and good fresh water is available, fill up the reserve feed tanks.

In the Engine-room.—Prepare all worsteds for use, see that those requiring it are washed in soda water, and that all are properly wired and weighted with small pellets of lead to prevent them working through the oil ways. A sketch of a worsted is shown; it should be of sufficient length. The wire is thrust into the oil pipe of the bearing, and the lead remains immersed in the oil.

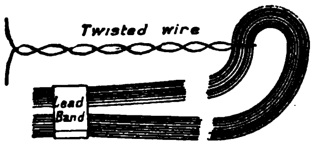

Fig. 1.—Worsted for lubricator pot.

Oil down all bright parts liable to be splashed by water.

Prepare all engine-room lamps.

Overhaul and oil the indicators, fit the proper springs on the pistons, adjust the strings, put the indicators in place.

Connect up the revolution counters.

Try all auxiliary engines, by steam, if possible.

Work the inlet and outlet valves of the circulating engines, Try all bulkhead and regulating stop valves that can be safely moved without admitting steam to the engines. In closing these valves they should only just feel their seatings, and should on no account be jammed tight, or they may set fast when heated by the steam next day.

The engineer will see the main engines oiled and turned through a revolution by the turning engine, or as much as convenient by the hand gear.

Oil the slide valves, and move them by the hand reversing gear. Oil the weigh shaft bearings.

Take out the hand reversing gear and put in the steam gear.

Take out the turning gear for the main engines.

Rig a hose in each engine-room to supply water to a hot bearing in case of such an emergency. These hose are generally attached to the fire main.

See that the friction brake in the screw alley, if fitted, is slack and free.

The above preparations, when carried out, should be reported to the head of the department.

Forced Draught Working.—If the boilers are to be worked under F.D., with closed stokeholds, the following points should be observed on the day previous to lighting up:—

The air-gauge U-tubes should be examined, cleaned, and filled with the water required.

The doors of all air-locks should be cleared and rigged.

The fans should be carefully oiled, adjusted, and tried by steam.

The louvres at the openings of the ventilation trunks, in connection with the bunkers in use, should be closed, to prevent coal dust being blown through by the S.H. air pressure on to the upper deck.

Ships lying in the "Reserve."*—A few days previous to raising steam in any ship which has been lying in reserve, the following precautions are to be taken:—An examination of the following parts, and all the gear in connection with them, is to be made; and whenever possible they are to be actually worked to test their fitness for service, viz.:—

All boiler mountings; slots of internal steam pipes; main stop valves, throttle, expansion, and slide valves; auxiliary slides, blow-through valves, relief and escape valves; starting gear, hand and steam; sea suction and discharge valves in connection with condenser, main engine pumps and auxiliary pumps; all shaft couplings, nuts, keys, &c.; all important holding-down bolts and other fastenings of machinery are to be examined and carefully sounded. Water is to be let into the condensers to ascertain the condition of the tubes. Pistons, junk rings and fastenings, and nuts and guards of rods are to be examined.

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* Art. 382, *Steam Manual.*

Example of a Routine for Lighting Fires and Raising Steam in Tank Boilers.—The time allowed to raise steam in a boiler of from 14 feet to 18 feet in diameter varies, according to the practice of the Chief, from six to twenty-four hours.*

It can be effected with safety in six hours in a commissioned ship, if the following routine be carried out; the routine is arranged so that the boiler shall be gradually and uniformly warmed, and supposes that the men are thoroughly familiar with the machinery.

(It will be found of great benefit to post a copy of this, or a similar routine on a notice-board in a conspicuous part of the engine-room):—

Sequence of Duties—*First Hour.*—(1) See that the water level in all boilers is at the right height, and that the test cocks are clear and properly opened. (2) Open the air cocks on the boilers and lift the safety valves slightly, to enable the warm air to escape. (3) Light the bottom fires; as previously mentioned, firewood is not necessary if a sufficient supply of live coal is at hand. It is worth while to light up one or more boilers earlier to provide live coal for the remainder. (4) If there is no pressure in the main steam pipes open the main stop valves on the boilers half a turn; the water lying in the pipes can then drain back to the boilers. If there are no separate auxiliary stop valves on the boilers, some part of the main steam pipes will be already under pressure from the boiler in use for auxiliary purposes; the main stop valves on the steam pipe so affected should not be opened until the pressure in the boilers is equal to that in the steam pipe. (5) See that all pressure gauge cocks are open. (6) Before lighting fires, open all drains on main steam pipes and valves, and leave open until steam begins to blow through. (7) When steam blows from the air cocks, close them and the safety valves also. (8) See that the turning gear for the main engines has been taken out. (9) Open the inlet and outlet valves and sluices for the circulating water supplied to the main condensers, and see that the spindles turn with the handles; these latter are often secured by pins which have been found sheared on some occasions. (10) Slack away the funnel guys. (11) Examine all lubricators; see that they are filled and all plugs removed from the oil pipes; see that all worsteds are in readiness. Do not forget to prepare the bearings in the screw alley. (12) Open the hot well delivery valves and the suction and delivery valves of the feed pumps, and also any intermediate valves on the feed pipes. It is as well to see that the sea suction valves of the auxiliary feed pumps are properly shut, and that the suction valves from the reserve fresh-water tanks are open. (13) Remove all gaskets placed to keep dirt out of the bearings, and also all other temporary covers which have the same object.

Second Hour.—(1) Light the top fires. (2) Open the steam-jacket admission and drain valves, half a turn, to warm and clear the steam jackets. (3) Examine the crank pits and clear away all obstructions from the machinery; see also that the bilge suctions from the pumps are clear of dirt. (4) See that the friction brakes in the screw alley are loose. (5) Examine and tighten the check screws on all the crank head and gudgeon bearings and the set nuts and split pins of the eccentric sheaves. (6) From this time forward, allow no one to get into the crank pits, and keep everything clear of the moving parts of the machinery. (7) Start the drain tank engine as soon as steam is available.

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* In cases of necessity, the time required can be considerably shortened by the extended use of firewood as fuel.

Third Hour.—(1) Spread the bottom fires. (2) Try the water gauge glasses and test cocks on the boilers as soon as there is steam enough. (3) Open the valves slightly on the main steam pipes which admit steam to the engine-room main steam pipes. Open all drains on the main engines, and try and save the discharged fresh water, by using the alternative connections and not those leading to the bilges. (4) Start the main circulating engines as soon as steam is available. (*N.B.* For the precautions to be observed in starting small engines see *Harbour Duties.*) (5) Open the water-service inlet valve and try if the water-service pipes are clear.

Fourth Hour.—(1) Spread the top fires. (2) Open the steam-jacket admission valve so that more steam is available for warming the main engines. (3) Work the equilibrium, manœuvring, and auxiliary starting valves. (4) Put steam on the reversing engine and run the slides up and down from time to time. Leave the equilibrium valve rather slack on its seating.

Fifth Hour.—(1) Open the bulkhead and master stop valves. (2) Try all the feed engines (sooner, if there is sufficient pressure). (3) Lift all safety valves by the hand gear till they are heard to roar; send a responsible man on deck to count the blasts to make sure that the valves lift on each boiler. (4) Put the engine tell-tales in gear. (5) Work the engine-room telegraphs. (6) See that the locking bolts in the rudder head have been taken out. (7) Prepare and try the capstan and steering engines. Put steam on the syren and whistle; drain and try them. Report in detail to the chief engineer that these duties have been carried out satisfactorily. (8) Slack back the stern glands the requisite amount—that is, until water drips through them.

Sixth Hour.—(1) Open the boiler stop valves the requisite amount. There is less risk of priming if these valves are opened no more than is necessary. (2) Open wide the bulkhead and master stop valves at least one hour before the engines are moved. (3) Put all worsteds in the oil pipes about half an hour before moving the engines. (4) Pump out the main condensers just before moving the engines, to ensure that the air pumps are not drowned, otherwise the inertia of the column of water to be moved may carry away the pump bucket or connections. (5) Keep all the drains leading from the main engines open until the ship is under way, in case any water comes over at first from the boilers or steam pipes. (6) Obtain permission from the chief and then try the engines, a few revolutions only each way; avoid putting way on the ship. Start the engines as slowly as possible; do not open the regulating or throttle valve more than half a turn, and use the manœuvring valve, if fitted. Use the auxiliary starting valves to test their condition. Remember that if there is any accumulation of water in the steam pipes or cylinders, it may cause much damage if suddenly put in motion. (7) Adjust the funnel guys.

The engineer responsible should personally see all these duties carried out. Especially must he supervise the connecting up of boilers.

Log the essential points of this routine in the engine-room register, and the time at which they were carried out.

Notes Concerning the above Routine.—If it is not possible to open the main stop valves on the boilers on lighting up, as when no auxiliary stop valves are fitted on the boilers, then the main stop valves should be eased half a turn in the fifth hour, when the steam pressure has probably risen to the working pressure in the boiler in use for auxiliary purposes. If a stop valve is found jammed, do not allow a "samson" to be used on the wheel, but proceed as follows:—Slack back the gland round the valve spindle and squirt oil through the gland, which, however, must not be released from the studs or stuffing box. Endeavour to free the spindle gradually by repeated motions, thus enlarging the arc through which the wheel turns. Tap the outside of the valve box to set up a vibration whilst moving the wheel. If, in consequence of expansion, the screwed spindle is jammed between the thread in the bridge and the valve seating, the nuts on the studs securing the bridge must be slacked back.

If the wheel and sleeve screw of a self-closing valve move back and the spindle does not follow, the spindle may subsequently be violently driven back by the steam. To prevent this accident make sure that the spindle is free and moves back gradually with the sleeve. A piece of brass plate bent into a U may be placed around the spindle between the wheel and the T head of the spindle, so that the wheel forces back the T head.

The average time taken to raise steam in boilers of different types is as follows:—

Cylindrical tank boilers with return tubes,	6 to 12	hours.
Cylindrical boilers with continuous tubes,	8	,,
Locomotive boilers, ...	6 to 8	,,
Water-tube boilers with large tubes, . .	2	,,
Water-tube boilers with small tubes, .	2	,,
Boilers of steam boats (locomotive type), .	2 to 3	,,

The time required in the case of water-tube boilers is that required to warm the engines. Steam can be raised in some of these boilers in thirty minutes.

Raising Steam in Water-Tube Boilers.—Steam at working pressure can be raised in these boilers in one hour or less, observing that if there is any new brickwork the boilers should be warmed more slowly. It is, however, advisable, under ordinary circumstances, to allow at least three hours for warming up the main engines. If the circumstances are exceptional, and the ship is not moored, the time required for preparing the engines for sea can be considerably shortened (to one hour or less) by keeping the main engines hot by means of a small steam supply from those boilers alight, the necessary preparation being thus reduced to the work of raising steam in the additional boilers required for steaming.

The number of boilers ordinarily in use for harbour purposes is not sufficient to supply the extra steam required to warm up the main engines (if these latter are cold) and further to provide for the additional requirements of the boat hoist and capstan engine, and it is generally necessary to light up additional boilers to be ready for these services.

The total time required to prepare for sea, if the circumstances are not exceptional, is, therefore, from three to four hours; and the following routine is suggested for a ship with Belleville or similar boilers. It is assumed that two boilers will be alight for harbour service, and that two additional boilers will be required for warming main engines, and two more for working the boat hoist, capstan engine, main circulating engines, &c. :—

Check over the preparations to be made on the day previous to sailing, see p. 31, *et seq*.

First Hour.—Open the air cocks on the boilers to be lit up to warm main engines; place the cocks of the pressure gauges in the blow through position.

Lift and close the safety valves before lighting up.

Light the fires at the middle furnaces of the boilers to be used for warming main engines.

Open the drains on the steam pipes and stop valves.

Ease the main steam stop valves on the boilers lit up, and all large stop valves in the run of the main steam pipes connected thereto, including the engine master valves, leaving them just off their seatings.

Open the suction and delivery valves of the feed and hot-well pumps.

Tighten up any boiler hand-hole doors which have been removed for examinations since the boilers were last used.

Close the air cocks, drain valves, and pressure-gauge cocks when they blow steam.

Second Hour.—Light up the middle fires of the boilers to be used for the capstan engine, &c., taking the precautions detailed in first hour.

Spread the fires in the first two boilers lit up.

Try the water gauges on the boilers, test cocks, and feed pumps as soon as there is sufficient steam pressure.

Examine and clear crank pits, and examine and try check screws and nuts, split pins, &c., on the bolts of bearings. Open the inlet and outlet valves of the main circulating engines.

Fill all lubricator boxes and examine worsteds.

Remove all gaskets from bearings.

Warm up, drain, and start the main circulating engines, and try the air cocks on the centrifugal pump casings.

Open the steam-jacket drains, also those of the engine steam valves, cylinders, and slide-valve casings. Open the jacket steam valves slightly. Start the drain tank pump.

Open out the stop valves of boilers to be used for warming up the main engines. Open the drains on the capstan engine. Open the stop valves and drain cocks of the capstan engine and warm it up gradually. Try the capstan engine.

Open out the auxiliary exhaust pipes on both auxiliary condensers.

Open out the steam supply and drain cocks, and warm up and try the boat-hoist engine.

Third Hour.—Light the centre fires of the remaining boilers to be used for steaming, observing the precautions previously detailed in first hour.

Spread the fires in the boilers for capstan engine, &c., and connect to auxiliary, when the steam pressures are equal to that in the auxiliary pipe.

Open out the steam valves to the cylinder jackets.

See that the locking bolts are withdrawn from the rudder head. Examine the controlling gear shafting (see Art. 127, *S.M.*). Warm up and try the steering engine and helm indicators, and try the telemotor gear.

Slack back the stern gland and open the water cock thereon.

Open the inlet valves on the water service and wash through the pipes, discharging the water into the bilge.

Keep the main condensers pumped out until the main engines are running.

Warm up the reversing engine and run the links to and fro to try the valve rods, &c., and to assist in warming the main engines.

Test the spindles and gearing on the equilibrium, manœuvring and starting valves with caution.

Open the relief cocks at the backs of the equilibrium rings on the flat slide valves of the main engines.

Fix up the indicators and gear on the main engines.

Try the automatic feed gear of all boilers lit up.

Fourth Hour.—Spread the fires in the remaining boilers lit up.

Try the engine-room telegraphs and syrens.

Put in all worsteds.

Ease and open out the boiler, main sectional, and bulkhead stop valves of the steaming boilers, and those of the auxiliary boilers, as the steam pressure becomes equal to that on the main engines. Open out the master valves to the main engines.

Try the main engines, after permission has been obtained and a final look round has been made.

Adjust the funnel guys.

Warm and try the fan engines and air blowers required for use.

Test the automatic blow-off gear on the main separators.

When connecting-up boilers to the engines, the operations of opening out must be carefully thought out to prevent any possibility of an accumulation of condensed water in a run of cold steam pipes (see p. 81).

To try the **engine-room telegraphs,** send a responsible man, an engineer if available, to work the lever on the bridge pedestal. The telegraph should be worked from "Full speed ahead" to "Full speed astern," and then to "Half speed ahead" followed by "Half speed astern," and so on in a definite order, so that the engineer in the engine-room can follow the motions and see that the hand on the engine-room dial correctly registers the orders; the handles on the pedestal should be moved through an angle sufficiently large to ring the gongs and attract attention below. In recent telegraphs, one turn of the actuating wheel on the bridge moves the pointer through one division on the engine-room dial.

When **trying the steam syren and whistle** it is as well to see that no one is near the apparatus, as a considerable quantity of scalding water is often discharged if the drainage of the steam pipe supplying them has been imperfect.

Routine for Connecting up the Steering Engine.—Connect up all the shafting, and see that no clothing or other gear is hung on the shafting, or is likely to foul the mitre wheels.

Put steam on the engine to warm it, and open the drains.

Put the indicators of all the controlling boxes amidships by means of the steering wheels.

Connect the hand steering gear; take out the locking bolts in the rudder head.

Put the helm amidships by means of the hand steering gear.

Set the indicator on the engine controlling-box amidships, by turning the engines by the hand lever.

Connect up the steam steering gear and try it.

Take out the hand steering gear when the ship is clear of the harbour. Warn the attendant to keep clear of the hand steering wheels whilst they are connected.

The following form will be found a convenient and reliable method of transmitting to the Department the necessary orders regarding raising steam:—

H.M.S. "................................"

ORDERS FOR RAISING STEAM.

..............*day, the*.................*of*.................*189*......

.................and Light Fires in Nos..................Boilers at.............m.,
.................Watch to be called at............m.

Capstan Engine to be ready for use and reported to Senior Engineer at............m., and afterwards to the Commander. Telegraphs, Whistle, Syren, and Steering Engine to be ready and reported to Chief Engineer at............m. by Mr......................., Assistant Engineer.

Funnel Guys to be seen at proper adjustment by............, Chief Stoker.
Try Check Screws of Crank and Crosshead Nuts in...............Watch.
Examine Crank Pits and clear up all loose gear in...............Watch.

[Line for Special Orders.]

Drain Engines and Steam Pipes carefully.
Carry out the routine, as posted on Notice Board, strictly.
Main Engines to be ready for trial at.....................
Bunkers to be used as follows:—Starboard,...............Port,...............

These Orders are to be initialed by
Messrs. N., M., &c., ...*Engineers.*
...............C.E.R.A. for E.R.A's. ....
..............Ch. S. for others concerned. ....
and returned to me.

(Signed) M. or N.,
.................*Engineer.*

Getting Underway.—Leave all drains open until the engines have run about 200 revolutions. If there is much starting and stopping, it will be as well to leave the low-pressure cylinder and slide-valve drains open to the condenser until the ship is clear of the harbour; they have little or no effect on the vacuum when running, and the practice will ensure that the cylinders are drained.

In starting the engines do not be hurried nor give excited orders; the evolution requires smartness, but it is part of the ordinary routine, and it should be taken as a matter of course that the engines will obey the levers if properly moved. Give the link time to run over before opening out the steam regulating valve and endeavour to open out smartly to such an extent that the engines will move off steadily. If the engines stick, do not open out the regulating valve wide before trying the effect of the auxiliary starting valves; the result of such a hasty action will probably be damage done to the air-pump gear, or to the piston and piston-rod, through the engines bursting off at speed.

The starting of some engines needs experience only to be gained by practice, but in general the routine should be somewhat as follows:—

1. Answer the signal from the bridge and run the link into full gear.
2. When the link is over, open out the regulating valve.
3. If necessary, use the auxiliary starting valves.
4. If the engines do not start, run the link quickly to full gear astern and back to ahead (or *vice versâ*), and again use the auxiliary starting valves.
5. Telegraph to the stokehold. (This can be done by an attendant.)

On first starting the engines, station an attendant with a long, clean tar brush and syringe to supply oil to all the piston and slide-valve rods.

When the ship is clear and the engines are running at the speed ordered the following adjustments should be made:—

1. Regulate the supply of circulating water to the main condensers. The temperature of the feed water in the hot well should be about 120° F. A higher temperature can be attained by reducing the amount of circulating water, but the packing of the condenser tubes might suffer. The temperature of the feed water in the feed tanks can be raised, with advantage as regards economy in consumption of fuel, by leading the discharge from the jackets and evaporator steam coils into the feed tanks; but the feed pumps may begin to give trouble when the temperature is over about 130° F., unless special arrangements are made (see *Feed Heaters*).
2. Adjust the pressure in the steam-jackets, and see that the jacket drains are clear and opened sufficiently.
3. Adjust the water service for the bearings. At moderate speeds no water should be required in any of the bearings, but it is usual to wash the outside of the eccentric straps and the outside cover of the thrust block

with a steady and constant supply. The new pattern open thrust block with horseshoe collars should need no cooling water.

4. Adjust the speed of the feed pumps.
5. Rig suitable temporary splash plates, firmly secured, in front of the cranks and eccentrics, to maintain the cleanliness of the engine-room.
6. Make a round of the bearings and ascertain personally that all are running cool.
7. Visit the stokeholds and inspect the water-gauge glasses. Try the test cocks. See that the fires are of the proper thickness, and the draught plates adjusted to uniformly distribute the work amongst the boilers.
8. See that the particulars of starting and stopping are copied correctly into the engine-room register.

Lead of Cylinder- and Slide-casing Drains.—The Admiralty specifications order the various drains to be led as follows:—The drain pipes are to be carried to the bottom of a switch cock. From each switch cock pipes are to be led, communicating with the auxiliary exhaust pipe and bilge for the high- and intermediate-pressure cylinders, and with the steam side of the main condensers and bilge for the low-pressure cylinders, non-return valves being fitted on the pipes leading to the bilge from the low-pressure cylinders. The pipes should be so fitted that there is a continuous downward lead to the discharge. The handles of all these cocks are to be brought into such positions that they can be conveniently worked from the starting position.

It is important that the drain pipes from each cylinder should have a separate lead. If the cylinder- and valve-casing drains are joined into one pipe the diameter should be correspondingly increased. It may well be that much of the difficulty experienced in starting certain main engines is due to the accumulation of water caused by bad drain arrangements. In two separate cases, to the author's knowledge, such difficulty has been removed by an increase in the size of the drain pipes together with the arrangement of leads specified above. It is a well-known fact, that auxiliary engines will not start at all until the water, accumulated in the auxiliary steam pipe and cylinders, has been removed by a continued use of the hand turning gear, by means of which the water is pumped into the drains or into the auxiliary exhaust pipe by the steam piston.

Working up to "Full Speed."—When the telegraph is put to full speed, the engines should be worked up gradually, the speed should be increased at regular intervals, and the conditions of lubrication adjusted as required. In this way the boiler attendants have time to increase the rate of combustion, and, consequently, the supply of steam to the extent required. If the speed be increased too rapidly the increase of ebullition in the boilers may cause them to prime, owing to a sudden reduction of steam pressure, and the engineer will find himself compelled to slow down whilst the fires are being shaken up and the steam pressure restored.

More care is required with cylindrical return-tube boilers, which are not capable of such rapid changes in the rate of combustion as are the types of boilers known as "water-tube."

The speed of the engines cannot be increased for a lengthened period unless the fires are thickened and quickened. The increase of speed should, therefore, follow the improvement of the fires.

When working up to full speed for the purpose of running a trial, it is usual to take from one to two hours in the process, so that everything may be examined and adjusted to secure favourable conditions. The link is set in its proper position and then the speed of the engines is increased by opening out the stop valve, by successive increments, as the pressure rises.

The above remarks do not apply to "express" water-tube boilers, which hold a so much smaller quantity of water that the pressure can be regulated with great facility, and speed can be increased or decreased in a few minutes.

CHAPTER V.

DUTIES OF A STEAMING WATCH—ENGINES.

It will be found of considerable benefit to post a set of orders under this head in the Engine-Room.

The duties and responsibilities of the engineer officer of the watch are alluded to in Arts. 134 to 139 of the *Steam Manual.* They comprise:—

1. The responsibility for the efficient working and proper management of the machinery and boilers in use.
2. The control of the men employed in the department.
3. The supervision of the expenditure of the necessary stores.
4. Entering a record of the working of the machinery in the engine-room register.

On Taking Charge.—The engineer about to take the charge of a watch is to satisfy himself by a careful personal inspection—

(*a*) That all bearings are working well and are in a proper state of lubrication.
(*b*) That the water in the boilers is at the proper working height, and that the density does not exceed the limit allowed.
(*c*) As to what cocks and valves are open.
(*d*) The depth of water in the bilge.

To carry out this inspection the relieving officer should be in the department before the time appointed for relief, so that he may be prepared to take over watchkeeping duties promptly and punctually. The relieving engineer should carefully read the entries made in the register since his last watch, and should receive from the officer on watch an account of the working of the machinery, especially with regard to difficulties encountered; and he should also carefully note any orders which have to be carried out at future appointed times.

It is usual to hang up a list of such bearings as require special attention, in consequence of recent adjustments, for the information of the watchkeepers.

Any orders received by the E.O. of the watch should be written in the register for the information of the successive relieving officers.

All defects of parts of machinery should be entered on a proper list, which will be available when opportunity arrives to take work in hand. This list may be temporarily pasted in the register. Any undue heating of the rods or bearings should be entered in the register, and the attention of the engineer relieving the watch should be specially drawn to the account.

If any part of the machinery is not in its normal condition of working when the relief watch comes down, the "watch on" should stay down until the matter is put right. The engineer in charge of the "watch on" is responsible until his relief signifies that he has satisfied himself the machinery is in proper working order.

The petty officers in charge of departments should, as soon as possible, report to the engineer of the watch that they have entered on their duties and found the machinery in proper condition.

The engineer of the watch should go round all bearings at least once an hour and personally ascertain that they are cool and in a proper state of lubrication. A soapy lather issuing from the bearings is a good sign of efficient lubrication, but the lather should not be too stiff; at certain speeds it is beneficial to supply a little water to the journals to thin the oil and prevent a stiff or thick lather being formed. The splash thrown out by a bearing furnishes a good idea of the condition of internal surfaces not accessible to the touch; the fluid so splashed out should be thin and milky in appearance, and the engineer should be careful to notice any increase in its temperature. Undue heating of a bearing can be readily detected in this way.

Considerable dexterity is often displayed by the stoker when feeling the moving parts, such as the crossheads, crankheads, &c. The engineer should also acquire this dexterity, but considerable care is required in the operation, and many personal injuries have resulted from careless procedure.

Rods which look bright after being oiled are in good working condition; oil applied to a hot rod becomes blackened by heat, and the peculiar penetrating smell of burnt oil will be detected. The origin of a smell of burnt oil should be immediately investigated. A bent piston or slide rod is sometimes first betrayed by the fact of its working warm.

Water Service.—The amount of water required by bearings depends on the particular set of engines. Most engines of modern construction require very little or none in the bearings when running below half power. The outside of the eccentric straps and the outside of the thrust block are kept cool by water jets, which are generally beneficial, even at low speeds. At high speeds a little water in the bearings will serve to thin the oil and prevent a thick lather being formed; the consumption of oil is also not so great under these circumstances. A very little water is sufficient, just enough to cause the ejection of a milky spray; an excess of water will wash the oil out and cause the bearing to heat. The question of the amount and nature of the lubrication required by a bearing is peculiar to the particular bearing, and these peculiarities should be thoroughly understood both by the engineer and the immediate attendant.

Lubrication of Bearings.—The oil cups of lubricators require special attention. They may become filled with water, splashed from the bearings or leaking from rod glands, and the oil contained will float on the water—thereby producing the appearance of a full lubricator. To prevent the supply of oil being diminished by this cause the E.O. should dip his hand in the lubricator and observe the appearance of its contents as the liquid runs from his fingers. The water present may be withdrawn by inserting a syringe to the bottom of the oil cup. To prevent the displacement of the oil from this cause, the caps of lubricators in exposed positions should be kept in place on the oil cup, and should be withdrawn only for examination or replenishing. The pipes leading from the oil boxes to the bearings should be examined from time to time, as they are liable to be displaced, especially during such times as the engines are under repair. These pipes should be washed through, at intervals, with soda solution, being taken down for that purpose. The bearings of the shafting in the screw alley are generally lubricated with tallow; if the tallow is simply placed in the box, which generally has no bottom, it will rest on the revolving shaft and will be wastefully expended. A good plan is to fit a tin bridge in the box, on which the tallow can be placed; the amount expended can then be regulated to the requirements of the bearing.

The water dripping from the stern gland should be tested from time to time; if it is warm, open the circuit cock and increase the flow through the stern tube. The stern gland should be so adjusted as to freely drip salt water of a temperature a little above that of the sea.

Many of the bearings on a set of engines are now lubricated from one central oil box, accessible from the top platform and generally secured to the cylinder. At one time this oil box was fitted with a number of cocks, through which the oil dripped into funnels made in the top of the oil pipes leading to the various bearings. It was found, however, that the drip was not constant, and the more recent plan is to supply the oil by means of worsteds arranged so as to give a visible drip. A means is provided of shutting off the supply; for this purpose a long plug is fitted with holes corresponding to each oil pipe; by turning the plug through 90°, all the drips are stopped.

This arrangement gives greater control over the supply of oil, and there is less danger of an isolated oil cup being overlooked. In this manner, rubbing surfaces, moving in a vertical line, are lubricated—such as the crosshead bearings, the guide surfaces, and the glands of piston- and slide-valve rods. All branches from lubricator boxes should be clearly marked to indicate the lead of the pipe and the part supplied.

The crank-pin bearings are generally supplied from centrifugal lubricators, which are particularly convenient for the hollow crank pins of fluid compressed steel now used in the best class of work. The oil is supplied to an annular copper saucer, the rim of which curves over to form a recess, made in two halves bolted together around the shaft and secured to the crank arm. The supply pipe from the oil box conducts the drops of oil into the open annular recessed rim. By the centrifugal force due to the rotation of the crank, the oil is thrown against the curved-over outside rim of the copper vessel, and so through a neck-piece led along the crank arm and joined to a pipe running along the hollow pin into proper holes bored through from the surface of the crank pin. The same fitting is also employed to lubricate the eccentric-strap bearing. This device is supplemented by an oil cup fitted high up on the connecting- or eccentric-rod, from which a pipe runs down to the bearing; in such an arrangement the radial acceleration tends to whirl the oil away from the bearing, and the weight of oil in the pipe is relied upon to overcome this influence. This arrangement is useful at slow speeds. The oil pipe supplying the centrifugal lubricator should be carefully adjusted so that it does not rub. The author has seen a case where this oil pipe had cut through the inner flat side of the centrifugal lubricator, and it was evident that the end of the pipe was bearing hard so that no oil was supplied to the crank pin.

The engineer should pay particular attention to the worsteds in the oil cups. They may be accidentally displaced or be of unsuitable length; worsteds will sometimes work their way down the oil pipes into the bearings, where they will be found filling up the oilway. This accident will involve the opening up of the bearing to clear the oilway when the ship reaches port, and may result in a hot bearing due to insufficient lubrication.

Lubricating Oil for External Use.—Owing partly to the high and increasing price of olive oil, the Admiralty have, to a certain extent, substituted rape-seed oil in its place, and have directed that a mixture of 60 per cent. rape seed and 40 per cent. mineral oil shall be tried for external use.

Economical Expenditure of Oil.—Leaks in the oil cups should be noted and promptly repaired, since they cause a wasteful expenditure of oil. The amount of oil used can easily be doubled by a very small drip. If the oil cup cannot be taken down at once and repaired, the leak may be temporarily stopped by a pellet of red lead applied outside the cup. Oil cups should be formed of solid castings, not of soldered sheet metal.

When a lubricator is fitted with a compartment for water, as well as one for oil, it is important that the division should be water-tight; otherwise the oil is floated out by the heavier fluid, and, for this reason, oil and water should never be supplied together to the same cup.

Oil need not be thrown away because it has passed once through a bearing. Many small engines are now built so that the connecting-rod and shaft are enclosed in a chamber in which the oil is allowed to accumulate, and the crank therefore works in a bath of oil which must pass many times through the bearings. In Parsons' turbo-generator the same oil is continuously pumped around the bearings of the turbine shaft. It is often possible to devise an arrangement by which the oil can be collected as it escapes from a bearing. A very efficient filter for waste oil can be made out of several thicknesses of flag bunting; the filtered oil can safely be used over again.

When cutting oilways in sliding surfaces remember that their true use is to act as channels for the supply of oil, and not to form reservoirs only.

The following plans for the economy of oil were described by Mr. W. Wilson, formerly chief engineer in the P. & O. Company's service, in a paper read before the Institute of Marine Engineers on February 24, 1891:—

"A trough is sometimes provided below the eccentrics, into which they dip at every revolution. The trough is generally filled with a mixture of water and oil; it is replenished by the oil and water draining down the rods from the glands and oil cups. A small drain cock is fitted so that a surplus can be drawn off and so prevent splashing. This arrangement has been found a certain cure for many bad-running eccentrics. A shallow packing gland may be fitted at each end of the thrust block, if of the old closed type. A gutterway is cut along the bottom half of the block, through the stationary collars, and not extending right through to each end; this gutterway becomes filled with oil, and so the shaft collars run in an oil bath. Plug holes are provided to draw off dirty oil.

"Another system consists in fixing a trough at each end of the block, on the bottom half, and extending as high as the centre of the shaft. The outside ends of the trough are formed of a light brass strip, bearing lightly on the shaft, but forming a joint half-way round so that the oil cannot escape. From the side of the forward trough, about 2 inches from the top, a pipe is carried round the front of the block to the bottom of the after trough, so as to give as great a droop to the pipe as possible. By this means the oil, after working through the block and reaching the forward trough, is sent back to the after one by gravitation. It may be observed that the oil is always travelling in a thrust block to the forward end. The working of the oil troughs is improved by fitting a light strip of brass on the top cap, in such a position that it just touches the after shaft collar and lies at such an angle to it that the oil picked up by the collar is diverted into the bearing, along the brass strip."

Thrust Collars.—If the oil be conducted to the rubbing surfaces at a point very near the shaft, it will be distributed outwards by centrifugal force; on the other hand, if the oilway be led in near the outer circumference of the shaft collars, the inner area may be insufficiently supplied with lubricant. Fig. 2 shows a well-lubricated thrust collar.

Thrust bearings require special attention under certain conditions. Thus the intensity of pressure varies as the I.H.P. ÷ speed of ship. Consequently, if the I.H.P. remains constant and the speed is decreased, then the intensity of pressure increases and additional lubrication is required. These circumstances occur when one ship is towing another, when steaming against a head wind or currents, and, more particularly during basin trials, when the ship is secured to the shore.

Lead of Oilways.—In order to secure good lubrication in a bearing, it is essential to provide a thick film of lubricant between the rubbing surfaces, and to keep it there; or otherwise, if it is not possible to prevent leakage, it is necessary to renew the wastage. The coefficient of friction of a bearing is decreased by thickening the lubricating film; this may be demonstrated by flooding a face plate with oil and placing a second face plate of smaller size upon the first. At the moment the oil is inclosed the film of oil is a thick one, and the upper face plate can be moved with the greatest ease. As, however, the oil is slowly pressed out from between the surfaces, the resistance to motion increases rapidly. The same effect is familiar to everyone who has flooded the bearings of a hand-power machine with oil.

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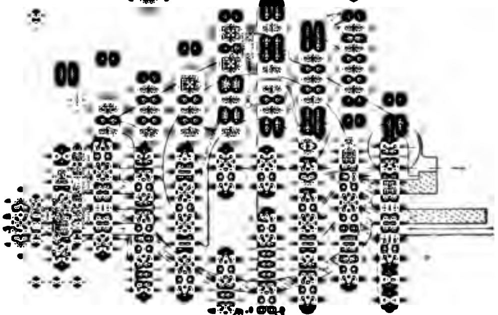

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[illegible] g face of a thrust [illegible] d of great benefit, [illegible] the collar, which [illegible] astern, should be [illegible] pposite hand."

[illegible] Beauchamp Tower [illegible] s (see *Proc.*, 1883, [illegible] good running of a [illegible] h the oil was sup- [illegible] to depend on the [illegible] supply as well as [illegible] experiments were [illegible] der a cap bearing [illegible] ould be varied as [illegible] on of the load was [illegible] ring was mainly in [illegible], to a less extent, towards the free edges of the cap. It was found that the intensity of pressure varied over the bearing, being a maximum at the crown, and that columns of oil of varying heights were supported in oil pipes whose orifices were led to different points of the circumference of the journal. Various methods of supplying the oil were tested, and showed that the maximum intensity of load which could be carried before the bearing seized varied with the mode of lubrication, other conditions being the same. Thus, when the oil was supplied by a pipe led to an oilway cut in the crown of the brass and parallel to the journal, the bearing seized at 100 lbs. per square inch. When the oil was supplied to two similar oilways cut in the horns of the cap and parallel to the journal, the bearing seized at 380 lbs. per square inch. When the oil was supplied by a pad touching the open under side of the journal, a load of 550 lbs. per square inch was reached; and, finally, when the under surface of the journal ran in a bath of oil, the bearing did not seize till a pressure of 620 lbs. per square inch was attained.

The following table is an abstract of some of the experiments conducted by the above committee:—

Conditions: Horizontal journal lubricated by a bath of oil touching the under side of the journal. A cap was pressed down on the journal, the nominal load being 520 lbs. per square inch. Temperature, 90° F.

Speed of Rubbing in ft. per minute.	157	209	262	314	366	419	471	Remarks.
Olive oil, . .	·0008	·001	·0012	·0013	·0014	·0015	·0017	
Sperm oil, .	·0015	·0017	·0018	·0019	·0020	·0021	·0021	Seized at 520 lbs.
Rape oil, . .	·00095	·0010	·00115	·00125	·00133	·00142	·00148	Seized at 573 lbs.
Mineral oil, .	·00123	·00139	·0015	·0016	·0017	·00178	...	Seized at 630 lbs. per sq. in.
	Values of coefficient of friction = *f*.							

If R × r is the resisting moment, then $R = fpA$, where p is the pressure on the journal in lbs. per square inch.

A is the area of the bearing = length × diameter.
r is the radius of the journal.

It was found that the coefficient of friction in the bearing for an oil pad was six times, and for a syphon seven times, the value of the coefficient for an oil bath.

The results found for a journal with a cap bearing under a load constant in direction and magnitude cannot be taken as applicable to the bearings of a marine steam engine where these conditions do not hold; on the contrary, the crankhead, crosshead, eccentric, and main bearings are subject to a load which is constantly reversed in direction at each stroke of the rods attached; the brasses are thereby alternately pressed against and withdrawn from the journals. If the means of supply of oil is suitable and sufficient, an opportunity is thus afforded in each revolution to cover the surfaces with oil and renew the wastage of the film before the pressure is subsequently reapplied; this action undoubtedly occurs, as is proved by the fact that the connecting-rod brasses of some large engines have run well without any oilways in the rubbing surfaces, though the omission can only be characterised as bad practice.

In marine engines, it is usual to fit the oil pipes to deliver at the top of the bearing; that is, in vertical engines, through the crown of the brass, as shown at *a*, *a*, Fig. 3. If there are two oil-supply pipes, as shown, it is better not to put them in communication, in order to avoid the free passage of the oil down one and up the other, as may sometimes be observed when filling the oil box of a main bearing. To this end, the oilways can conveniently be made to overlap, and so avoid the occurrence of a bare strip of rubbing surface. The bottom brass shows oilways designed to be fed from the clearance space in the horns of the brasses. The white metal or brass rubbing surface is not generally continued up the horns of the bearing, the pressure being taken on the crowns only, but it is essential to continue a narrow circumferential bearing strip at each end of the brass right up to the butting edge, as shown at *c*, *c*, in order to reduce the amount of oil squeezed out. To enable this boundary strip of white metal to be secured, a dovetailed recess should be cut or cast at each end of the brass around the circumference of the part of the horn left bare, the white metal filling this recess being made continuous with the layer over the rubbing surfaces. If the liners between the butts of the brasses were also made with a narrow circumferential

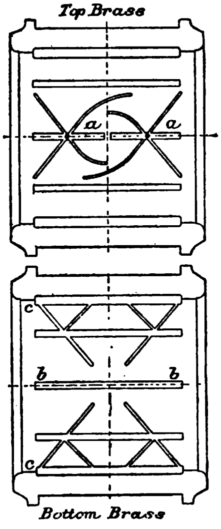

Fig. 3.

rubbing strip at each end of the brass, thus forming a continuous boundary at each end of the journal, it may be anticipated that less oil would be lost from the bearing, and that the necessary thick film of oil would be better preserved.

The groove or oilway *b b*, Fig. 3, is not usually cast in the lower brass itself, though experience has proved it to be of considerable benefit; this groove may be cut in the white metal, if the layer is thick enough to obviate any risk of splitting, but the better practice is to cast the groove in the brass, when it can be undercut to secure the white-metal layers efficiently. It should be mentioned that a certain amount of end play is necessary in all journal bearings to prevent the formation of circumferential grooves and corresponding ridges, which latter might produce excessive friction if suddenly displaced.

Supply of Oil.—The oil should be supplied to the bearings under a certain "head" or pressure. To this end, centrifugal lubricators are largely used, and are to be preferred to gravity pipes wherever they can be fitted. If the oil supply is furnished by worsteds, the oil boxes should be placed as high as is practicable above the bearings, and the oil pipes should be led into the solid brass without any interval to break the "head."

The amount of oil supplied by a worsted varies greatly with the level of oil in the box. Some experiments carried out by Engineer Commander Ayres in H.M.S. "Pandora" showed that the supply of oil varied as 4 : 1, with a difference of level of $\frac{3}{4}$ inch, from A to C in Fig. 4. The experiments also showed a great difference in the rate of supply of olive as compared to mineral oil; if the latter oil is largely intermixed with olive, the worsteds should consist of about twice the number of strands required for olive oil, and the oil pipes should be of a corresponding larger area.

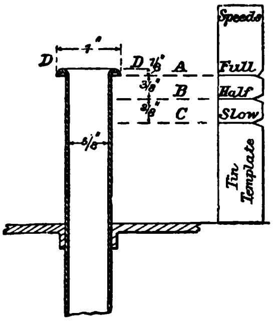

Fig. 4.

It follows that the steady supply of oil to a bearing depends very greatly on the constant care and attention paid to the level of the oil in the boxes, and that the oil level should be maintained at a fixed point.

It has been found economical and practicable to control the rate of supply of the lubricant by varying the level of oil in the boxes to suit the required power to be developed by the engines. For this purpose the oil boxes are fitted with a sliding shutter, which is used to adjust the height of the overflow from the box; the oil boxes are furnished with a continuous supply by means of a pump drawing from a tank to which the overflow oil returns.

If a simpler, though less exact, method is desired, the supply of oil can be regulated to a certain extent by varying the number of strands in the worsteds according to the I.H.P. developed. Each oil box should contain a tin template, with notches cut to show the proper level of oil to be maintained at full, half, and slow speeds (see Fig. 4).

Forced Lubrication.—Experiments made on the engines of torpedo-boat destroyers give reason to anticipate that the smooth working and small wear of rubbing surfaces experienced with electric light engines fitted with forced lubrication may also in the future be obtained by main propelling engines. In some electric light engines so fitted, it has been found that a quantity of oil has accumulated in the boilers, having been carried into the cylinders on the rods of the low-pressure cylinders. This trouble is minimised by feed-water filters and well-packed glands of good design, and can be prevented entirely by designing a longer piston-rod with more clearance space between the cylinder and the closed casing over the moving parts.

For some further notes on oilways, see Chapter XIX.

Internal Lubrication.—Very little or no oil is supplied to the cylinders in modern practice, even with horizontal engines. It is found that the steam is sufficiently wet to ensure lubrication; especially is this the case with the cylinders of auxiliary engines. The author served in a first-class battleship whose auxiliary engines had no lubricators on the cylinders or slide valves; they had been replaced by bolts screwed into the plug holes, and, throughout a three years' commission, these auxiliary engines ran perfectly, without any oil; the cylinders were opened out frequently, cleaned, and oiled out with the palm of the hand. A little oil is, however, always carried into the cylinders by the rods, and forms grease balls, which may be found in recesses such as those formed by the cylinder relief valves in the cylinder bottom. If these balls are allowed to remain they may choke the drain pipes; they should, therefore, be removed whenever the manhole doors are taken off.

Grunting of Slide Valves or Pistons.—If grunting occurs in the cylinder or slide valve the best method of lubrication is to apply a mixture of water, soft soap, and oil through the proper lubricating cocks. Very little oil is generally required in the mixture, and it is often advisable to try an application of water alone. The water so applied may cause a loss of economy by increased condensation, but it is often more important to the engineer to keep the feed-water free from oil, which might eventually be deposited in the boilers.

Drains of Auxiliary Engines.—If no oil is used for the internal lubrication of the auxiliary engines the water discharged from their drain pipes can safely be collected and used. The loss of feed-water through the drain pipes of auxiliary engines is serious, and in a very large ship may reach 4 or 5 tons in the twenty-four hours. It should, however, be carefully ensured that such drain-water is free from grease before it is allowed to reach the boilers. It may be noted that no lubricators are now fitted on the cylinders or steam pipes of the fast running main engines of torpedo boat destroyers.

Steam Traps.—The drain pipes from steam pipes and exhaust pipes are generally led to automatic steam traps. A common type consists of a brass box containing a floating vessel, which latter carries a conical valve fitting a seating made on a long hollow sleeve communicating with a discharge passage in the cover. The float keeps the aperture in the cover closed until the drain-water, which collects around it, overtops the brim and causes the float to sink; the valve then leaves the seating; and the water in the float is blown out by the steam pressure, whereupon the float is again borne up by the surrounding water.

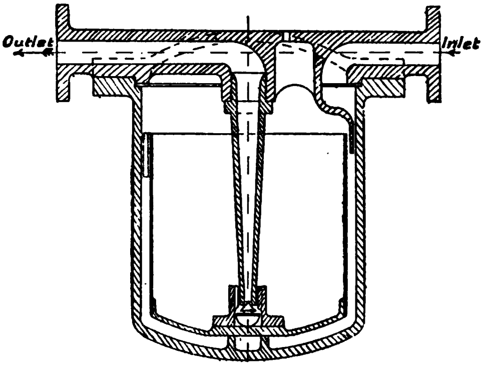

Fig. 5. —Steam trap.

It is necessary to remove the cover and float, and thoroughly clean the grease out of the interior of the trap at quarterly intervals.

The steam trap shown in the sketch is proportioned as follows:—

Steam pressure not to exceed 170 lbs. per square inch.

Valve open: weight of empty float, 12 lbs.; displacement, 15 lbs.; resultant force to close valve, 3 lbs.

Valve closed: weight of float when full, 26 lbs.; displacement and excess pressure on valve area, 19·6 lbs.; resultant force to open valve, 6·4 lbs.

The composition of the brass is not less than 8 per cent. tin, not more than 5 per cent. zinc, the remainder being copper of good quality.

Vacuum.—The engineer of the watch should pay attention to the amount of vacuum in the main condensers. A reduced vacuum is a fruitful source of loss of economy, and the cause should be investigated. The temperature of the feed-water delivered from the air pumps should be from 110° to 120° F., depending on the temperature of the sea water; and the speed of the circulating pump should be adjusted to produce this temperature. If the feed-water is too hot it is probable that there is not enough circulating water, and the vacuum will suffer. If, on the other hand, the feed-water is cool and the vacuum is bad, the fault is probably with the air-pump valves, or may be caused by an air leak into the condensers. It is then advisable to go round all drain valves on the condenser, air-pump and exhaust-steam pipes, and see that they are not open to the atmosphere; also, if the main circulating engine exhausts both to the main and auxiliary condensers, see that both exhaust valves are not open, and inspect the suction leading from the feed pumps to the condenser, if so fitted. Try the silent blow-off valve and the soda cock, and make sure they are shut. An imperfect vacuum may be due to leaky glands on the low-pressure cylinder, which need re-packing, or to a split in the low-pressure receiver pipe. In a certain case, an investigation as to the cause of a defective vacuum led to the discovery of cracks running round the bellows pieces provided for taking up the expansion and contraction of a low-pressure receiver pipe, ordinarily covered in by lagging. Examine the vacuum gauge, which may be defective or partially shut off; there are usually more gauges than one on which the vacuum may be read; if they all show a low reading the vacuum is most probably defective.

Air Pumps.—The glands of the air-pump rods generally hiss a little; they must not be tightened whilst running, except after consultation, for fear of heating the rods. The cups of the air-pump rod glands are generally kept filled with tallow, for lubrication and to secure air tightness. If these glands are well packed with gasket, very little of the tallow should find its way to the feed-water.

Density of Feed-water.—The feed-water in the feed tanks should be constantly *tasted* for brackishness; this is a fairly reliable test.* Should the water drawn off from the feed tank show a density as low as one-tenth,† or should it taste slightly brackish, it is necessary to take steps to ascertain the cause of the salt water leak. Such a leak, resulting in a rise in density of the water in the boilers, is generally occasioned by leaky condenser-tubes, and can then only be detected by opening up the condensers as detailed in the Chapter on *Adjustments*. There are, however, other causes, some of which may be found and remedied whilst under weigh.

1. The sea-suction valve of one of the feed pumps may not be properly closed.
2. The air pump may be fitted with an automatic spring-loaded discharge valve, delivering into the circulating water discharge pipe overboard. If this valve is leaky or is prevented from closing, salt water will leak back to the air pump during a temporary stoppage of the main engine. This automatic valve is fitted to relieve the air pumps of a glut of water on starting; also for the discharge of the salt water admitted to the condensers when the jet injection is in use. Jet injectors were formerly fitted to surface condensers, for use should the circulating pump be disabled.
3. If the evaporator primes when the vapour formed is being passed into the main or auxiliary condenser, the density of the water in the feed tanks will rise, since the density in the evaporator is high.
4. The supplementary salt water feed cock may be leaky.

Duplication of Centrifugal Pumps.—Jet injectors are not fitted to surface condensers in modern practice. They have been superseded by fitting the main circulating engines in duplicate, in each engine-room, or in such a manner that the pump in one engine-room can be used for both condensers. This latter arrangement is particularly convenient for the following reason. The inlet for circulating water will often become choked by jelly-fish or seaweed, and the water discharged from the condenser will have a high temperature due to its insufficient quantity. It is very convenient, in such a case, to be able to shut the discharge outlet on the affected condenser and discharge the water pumped from the other engine-room through the choked inlet, thus washing out the obstruction.

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* Nitrate of silver, if added to water containing even a trace of salt, produces a cloudy white precipitate.

† The hydrometer is so graduated that the density of sea water is 10 at 200° F.

Warm Bearings.—The causes of warm bearings are various.

Firstly.—The most frequent cause is probably the presence of dirt. To prevent an accumulation of dirt it is necessary to open the bearing and clean it from time to time, and to clean the oil pipes and cups; also the lubricating oil should be clean and supplied through clean vessels; if the engine-room be kept in a dirty state it is probable that the bearings will acquire the same condition.

Secondly.—Warm bearings may be caused by improper adjustment; cases from this cause are more frequent when the machinery is new and comparatively untried. In the case of moving parts, such as the crosshead and crankhead, it will be necessary to stop in order to re-adjust the bearing.

Thirdly.—Warm bearings may be caused by insufficient lubrication. This implies that the oilways are not sufficient, or they may be improperly placed; or the bearing may have been neglected. The two former reasons are not likely to apply to engines which have been some time in use; but, in new engines, an additional oilway or a better distribution will frequently produce a great improvement in the running. In the case of crank-head brasses the oil pipes should be led through the brass strip between the white metal areas; if led into the latter the white metal may be forced into and choke the oil pipe.

In the following remarks the author has endeavoured to give some advice to the inexperienced officer, but the case of a heated bearing cannot be generalised; it can only be hoped that such an occurrence will not be very frequently experienced, as it calls for great judgment and may end unfortunately. The remarks as to the application of a hose are especially important, and a certain responsibility is incurred whenever a hose is applied to an overheated part.

In the case of a bearing tending to warm up, act promptly, despatch a reliable messenger to the senior engineers to inform them of the emergency. The most usual treatment is to flood the bearing inside and out with water and so wash all dirt out and keep down its temperature. When the temperature is reduced introduce a copious supply of oil and give the bearing special attention until its condition is normal. In the case of a shaft bearing it may be advisable to slack back the nuts on the caps securing the top brass, which can be re-adjusted later. It is generally possible to alter the distribution of the power developed by the various cylinders, and so ease a particular bearing without altering the speed; this can be effected by running the link in or out and adjusting the main regulating valve correspondingly; and it is advisable to take diagrams at convenient opportunities from the various cylinders, with the special intention of finding the distribution of the work for various positions of the link and main regulating valve, keeping the total H.P. constant.

It may be necessary to ease the engines altogether whilst a bearing is being cooled; the chief engineer will generally have arrived in time to decide whether this course is necessary, and the proceeding should not be lightly undertaken as it reflects discredit on the department; it is, however, sometimes absolutely necessary to ease down the best-cared-for engines.

A bearing which is "running warm" should be given a more copious supply of oil, or should be fed through the oil pipes with a syringe from a bucket containing a mixture of oil, soft soap, and water, which has a specially soothing effect. The lubricator should be thoroughly cleaned out and replenished with clean oil before the special lubrication is discontinued.

Mr. Denton, in a paper read before the Society of American Mechanical Engineers, 1890, states that journal brasses with no reciprocating motion wear in parallel grooves. Such grooves are not inconsistent with a low coefficient of friction. If the grooves are displaced by a slight movement sideways the friction is greatly increased. Accidental variations of smoothness, infinitesimally small, may cause over-heating.

The effect of applying a grinding powder to a hot bearing is to convert the bearing surface into a series of parallel grooves, and the oil is then better distributed.

If a grinding material be applied to a cool bearing the coefficient of friction is increased. In one case the coefficient rose from 0·0025 to 0·09, and the temperature rose from 95° to 100° F. The grinding material was 60 per cent. soapstone and 40 per cent. grease.

The above paragraphs explain why it is important to increase the amount of lubricant supplied to the bearings on going astern, for it is evident that all the journals then shift in their brasses. The astern surfaces of the guides are generally of less area than the ahead, and it is advisable to use the water service upon them.

Effect of Water Douche.—There is no great risk to be apprehended from the supply of water to a bearing which is only beginning to warm up, and the engineer should apply his water service and hose promptly to prevent the brasses heating. On the other hand, an overheated bearing must be treated with far more consideration; the sudden application of a hose in such a case may cause cracks due to unequal contraction. An overheated bearing should be slacked back if possible. Experience alone will dictate the correct course, and the presence of the chief engineer should be immediately procured, whilst, in the meantime, a free application of oil by syringe can do no harm.

Hot Rods.—If a piston or slide rod is working warm, it should be freely lubricated by a tar brush and syringe from the bucket of soapy oil and water. An attendant should be kept at the duty. It is possible that the undue warmth may be caused by a tight gland which should be at once slacked back. The hose must on no account be played upon a hot rod; the effect will be to cause the side of the rod cooled by the jet of water to compress the unexposed hot side. Consequently, when the rod subsequently returns to its normal temperature, it will be permanently shortened on the side which escaped the water; that is to say, the rod will be bent, and must be removed to the shops and straightened. The foregoing result has been produced in practice, and the imprudent treatment severely condemned. If a really hot rod is suddenly discovered the engines must be eased. Warm guide surfaces can be generally restored to their normal condition by a jet of water from a hose applied to the back surface of the fixed guide.

Observation of Condition of Machinery.—The particular bearings which require adjustment should be determined whilst the engines are in motion. If a bearing is too loose it will knock at each end of the stroke. A knock can be located by the ear and sense of touch, but the best confirmation is obtained by flooding the suspected bearing from the internal water-service pipe. The effect of the water is to provide a cushion. The water is forced out at each end of the stroke in a spray, and the noise of the knock is no longer heard. Be careful to replace a sufficient quantity of oil in the bearing, after the water has been worked out, to compensate for that washed away.

A loud knocking in the cylinder itself may be due to a loose piston ring. Open the jacket drains to make sure that there is no accumulation of water in the jackets. If the noise is continuous at different speeds it may be attributed to the piston rings, and may be temporarily avoided by opening the auxiliary starting valve slightly, and so increasing the amount of cushion pressure. On the first opportunity a thin paper liner may be inserted between the spring ring and junk ring. This liner will not be of permanent benefit, but will serve to show if the spring ring is loose. If the liner fitted be too thick, a leaky piston will result. To refit the spring ring it will be necessary to scrape the face of the junk ring and so let it down nearer to the spring ring; it may be necessary to take a thin scrape off in a lathe, but such treatment will affect the fit of the spare ring. A knock in the piston may be due to the slacking-back of the piston-rod nut, and consequent looseness of the piston on the rod, but it is more general to find the piston too tight on the cone than too loose. In modern practice the piston rests on a collar formed on the rod at the base of the cone. All large nuts are made of wrought iron to prevent them seizing on the steel rods. A knock due to a broken spring ring should be apparent on the first examination. A further cause for a knock in the piston of a vertical engine is sometimes traced to a radial movement of the spring ring. The defect may be remedied by fitting cod pieces quadrantially between the piston body and the ring.

Pumping out Bilges.—A bilge pump should be kept constantly at work whilst the ship is steaming to pump out the bilges and crank pits. Such pumps have usually four or five suctions—namely, from the crank pits, the engine-room bilges, the stokehold bilges, the main drain, and the sea.

The crank pits should not communicate with the engine-room bilges, because the oil in the crank pits must not be spread over the bilges. The stokehold bilges can be emptied into those of the engine-room by means of a sluice valve on the bulkhead, but since there is always a quantity of small coal in the stokehold bilges, it is usual to pump out the latter direct through the longer suction pipe. It frequently happens that the strainer over the suction pipe in the bilge becomes choked with cotton waste, or articles carelessly left in the bilge; for that reason the strainer should be fitted in such a place that it can be easily examined and cleared.

It is a difficult matter to clear the strainer in the crank pits whilst the engines are in motion; and to meet such a case a tapped hole closed by a bolt is useful for draining a full crank pit into the bilge. If no such drain hole is available, the greasy water will be splashed over the plates by the revolving crank. Stokehold bilges need special attention because the fine coal dust stops the passage to the strainer, and it is continually necessary to clear the accumulation away. When the strainer is fitted behind the boilers, as is sometimes the case, it is practically inaccessible whilst the boilers are in use, and in such a case the water must be drained into the engine-rooms.

The latest practice with respect to stokehold bilge suctions is to form wells, recessed into the inner skin at the lowest part of the bilge; these wells are about 18 inches diameter and 8 inches deep, covered by strainers 24 inches in diameter and 10 inches in depth. The suction pipe is led through the strainer and dips into the well, terminating 2 inches below the level of the bilge. A mud box is fitted in the suction pipe in such a manner that a rod can be introduced for clearing the pipe. Fore and aft wash plates are fitted in the bilges to prevent the water from washing from side to side when the ship rolls. In ships with no inner skin, cement is laid in the bilges to give the water a run to the suction strainer.

A very slight obstruction under the valves of a bilge pump will throw it out of action; ordinary wooden matches have frequently been sufficient, and for this reason the engineer must maintain scrupulous cleanliness on the engine-room plates.

Steam Jackets.—The pressures in all steam-jackets should be watched and kept constantly at the designed amount. The drain valves require special attention, since, if water is allowed to collect in the jackets their usefulness is destroyed. On the other hand, steam should not be wastefully blown through the jacket drains.

The pressures in the various jackets being of different magnitude it is essential that they should be drained through separate pipes. The jacket drains are led into both the condenser and feed tanks, the latter is the better disposition on account of economy. The trials of the s.s. "Iona," initiated by a committee of the Institution of Mechanical Engineers in 1890, showed that the feed-water in the tanks was heated from 106° to 157° F. by the jacket drain water, and the consumption of coal was thus reduced from 1·46 to 1·38 lbs. per I.H.P. hour, a gain of economy of 5½ per cent. For the same reason the drain water from the evaporator steam coils should be led into the feed tanks near the bottom. If the water level in the tanks falls to the level of the entrance of these pipes considerable vibration is set up, and betrays the fact that the feed-water level is low. In modern engines the jacket drain pipes are each led through a receiver, fitted with a gauge-glass and a screw-down discharge valve, so that, with attention, no accumulation should occur in the jackets.

It should be remarked that the drains from the steam-jackets and evaporator steam coils have been led into the auxiliary condensers in recent warships; inconvenience has been experienced by the discharge of vapour from the open-ended overflow pipe fitted on the feed tank, and, in a warship, economy must often give way to expediency. In the older engines the jacket drain cocks must be adjusted by touch and ear; the pipes should be hot, but no rush of steam should be heard.

If water be present in the steam-jackets in any quantity, it will often set up a loud cracking noise or series of reports in each stroke. The remedy is to open the drains wide and discharge the water and afterwards readjust the opening allowed in the drain valve.

Jackets are often left out of use, either from a doubt as to their economy or from fear of scoring the piston ring or liner by the use of dry steam. It is instructive to calculate the apparent amount of water used per H.P. hour from each of the diagrams, when it will often be found that even if the steam is dry in the high- or intermediate-pressure cylinders it is half condensed in the low-pressure cylinder. Under such conditions it need not be feared that the use of the jackets will be prejudicial.

Economy of Steam Jackets.—In the *Proceedings of the Institution of Mechanical Engineers for* 1889-90, a series of about fifty experiments on this question are reported. In no case has the employment of a steam-jacket resulted in a loss, whilst the saving of feed-water effected by its use is often from 30 to 40 per cent., and generally between 10 and 20 per cent. The majority of these experiments were made on simple and compound engines, but in the following two cases, the details of which are here quoted, the engines were triple expansion:—

No. of Engine.	Authority.	Date.	Description of Engine.	Diameters of Cylinders.	Parts of Cylinders Jacketed.
				Inches.	
1	Reynolds, . .	1889	vertical inverted	5, 8, 12	All bodies, ends, and receivers.
2	Davey and Bryan Donkin,	1889	,,	18, 30·5, 51	All bodies, and ends.

No. of Engine.	Revolutions per minute.	Piston Speed, feet per minute.	No. of Expansions.	I.H.P.	Steam Pressure per square inch (gauge).		Total Feed-water.			Jacket Water per H.P. hour.
					Boiler.	Jackets.	Per H.P. hour without Jackets.	Saving due to Jackets.		
								Per H.P. hour.	Per cent.	
1	230 to 299	383 to 747	26·5	72·1	192	192	16·42	2·86	17·4	3·29
2	22·9	137·4	30	138·0	130	129 28 5	17·22	1·77	10·3	1·72

In the discussion which followed the above paper the following opinions were expressed:—

Mr. Bryan Donkin said the steam should be dry at release to attain maximum efficiency, and the jacket should be used to attain this end. Professor Unwin, F.R.S., also stated that the steam should be dry at release. Professor Kennedy, F.R.S., said that there was not space in many jackets for the steam to circulate, and, consequently, little improvement followed from their use.

Mr. Thornycroft, F.R.S., mentioned that French engineers sometimes take the steam for the auxiliary engines through the jackets of the main engines to ensure circulation in the latter.

Mr. Davey and Professor Unwin anticipated no difficulty on account of lubrication, since pistons and cylinders are now made of better metal.

Since the first edition of this book passed through the press, experiments have been made to determine the value of the steam jackets fitted to the cylinder barrels of engines of H.M. ships. Certain particulars of the engine design are given in the following tables, together with the actual results obtained :—

Name of Ship.	Description of Engines.	Number and Type of Boilers.	Diameter of Cylinders.	At Full Power.			
				Revolutions per Minute.	Piston Speed in Feet per Minute.	Steam Pressure at Engines.	I.H.P.
"Diana," .	Triple-expansion.	8 Scotch.	33″, 49″, 74″	146	949	146	9,875
"Argonaut," .	,,	30 Belleville.	34″, 55½″, 2 of 64″	128·4	1027	275	18,894

PARTICULARS OF TRIAL.

Name of Ship.	I.H.P. during the Trial.	Lbs. of Steam Used per I.H.P. per Hour, for Main Engines only.	Particulars as to Steam Jackets in Use.*	Steam Pressure in H.P. Receiver. Lbs. per Sq. Inch. Atmos.	Cut-off in H.P. Cylinder.	No. of Total Expansions.
"Diana,"	8,000	17·75	All.	145	·65	6·4
		17·94	L.P. only.	143	·65	6·4
		17·57	None.	144	·65	6·4
"Diana,"	6,400	18·06	All.	121	·60	6·8
		17·91	I.P. and L.P.	119	·60	6·8
		17·84	L.P. only.	117	·60	6·8
		17·45	None.	121	·60	6·8
"Diana,"	4,800	16·54	All.	128	·42	8·5
		16·8	I.P. and L.P.	124	·42	8·5
		16·45	None.	127	·42	8·5
"Diana,"	1,600	17·6	All.	76	·25	11·5
		17·7	H.P. and I.P.	78·5	·25	11·5
		19·2	None.	80·5	·25	11·5
"Argonaut,"	18,000	16·64	All.	237	·71	8·5
		16·15	L.P. only.	242	·71	8·5
		15·75	None.	236	·71	8·5
"Argonaut,"	13,500	15·85	All.	244	·43	12·5
		15·87	I.P. and L.P.	234	·53	10·4
		15·44	None.	230	·53	10·4
"Argonaut,"	3,600	16·32	All.	164	·27	15·7
		16·34	I.P. only.	166	·27	15·7
		16·26	None.	168	·27	15·7

The results of these experiments show that at powers above one-fifth of the full power the use of the steam jackets was attended by a loss of economy; though there is evidence that at lower powers a saving is obtained by their aid. This latter conclusion was confirmed by repeated trials made in H.M.S. "Diana" and "Hermes." It may be assumed that the jacket drains were very carefully attended to during these trials; it may very easily happen that the careless use of the jackets results in a considerable loss, if steam is blowing freely through the drains.

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* Only the barrels of the cylinders are jacketed.

The results of the above experiments should be considered as applicable only to engines of the Admiralty standard type; it should be noticed that they are at variance with the large number of experiments made on other types of engines by the Institution of Mechanical Engineers.

The Pressure in Steam Jackets.—As regards economy solely, it is desirable that the pressure in steam jackets should be greater than the initial pressure of the steam in the cylinder, since the object of the jacket is to keep the temperature of the cylinder walls not less than that of the entering steam. On the other hand, if no oil is used for internal lubrication, it is essential that the steam should be more or less wet, otherwise the surfaces of the liner and piston ring will be scored. The result is that a compromise is made, and the jacket pressure is adjusted at as high a figure as is consistent with smooth working.

Linking Up.—The best position of the link as regards the consumption of coal for a given number of revolutions is settled by experience; at low speeds the engines are linked up to obtain the benefit of an increased ratio of expansion, but the exact position is obtained by trial, so that the engines work smoothly without shock or undue noise. The bearings are then protected from damage by the adequate compression of the steam in the clearance spaces. As regards economy the regulating valve should be wide open, so that the steam pressure in the H.P. chest is as nearly equal to boiler pressure as possible.

In the best practice each reversing arm on the weigh shaft is slotted, and a block, actuated by a screw and wheel, moves in the slot. The drag links are attached to the block, the result being that each link can, to a certain extent, be independently adjusted. It will generally be best, when working below full power, to link up the H.P. engine to a higher degree than the others, by the use of the independent arm. The total ratio of expansion is thus increased, while the maximum opening of the I. and L.P. slide valve ports is not reduced to the same extent as if the links were moved by the common weigh shaft. There is then less loss by wiredrawing between the cylinders. In a well-designed gear the slot in each arm is so placed that it is approximately at right angles to the drag links when in full gear astern; the position of the block in the slot does not then affect the steam distribution. It is important that the block should be in full gear when the engines are being used for manœuvring the ship, otherwise there may be difficulty in starting them.

The proper compression, as regards economy alone, is attained when the diagrams show a little loop at the junction of the compression and steam lines, indicating that the steam in the clearance space is compressed to admission pressure before admission takes place; experience has shown that the use of this amount of compression conduces to the economical working of the engines, and the Admiralty have directed that engines are to be so linked-up when the ship is cruising. As an example, refer to the diagrams taken from H.M.S. "Powerful's" engines when working at 2500 H.P., each set, making a total of 5000 I.H.P. for the two sets together (see p. 67).

As a general rule, the engineer of the watch will have no occasion to permanently alter the position of the link unless orders are received for a change of speed during his watch, but it is advisable to drain the starting engine from time to time, and to let it run a few revolutions each way, to ensure that it will be ready for use should sudden orders be telegraphed to stop or go astern. This can generally be effected without altering the speed of the engines, and the link should be left as originally adjusted. Should grunting occur in the slide valves, it may often be stopped by giving the link a run and slightly varying its final position.

Indicator Diagrams.—It is usual for the engineer to take a set of diagrams in each watch if the engines are running at a regular speed. If the indicators are not rigged in position it is necessary to thoroughly clean them before setting them up. The pistons must be well oiled, because a little friction will materially reduce the power recorded. The springs selected for each cylinder should be such that the diagrams are as large as possible, in order to reduce errors of measurement, and will depend on the power at which the engines are running, or rather on the mean forward pressure in each cylinder. The sketches given represent to half size, diagrams taken from the engines of H.M.S. "Powerful," running at different speeds, and illustrate the various springs necessary. The springs supplied are carefully tested and are reliable for general purposes; but, for very accurate experiments it is usual to have the springs specially tested at the temperatures attained in practice. The string must be carefully adjusted, and should always have a sliding loop for this purpose; the revolving drum carrying the paper must not be brought up at either end by the stops, and the engineer should ascertain that it has clearance at each end of its oscillation; this is easily done whilst the drum is in motion.

If the drum brings up on the stop the end of the diagram will be too square, because the pencil performs a vertical movement whilst the drum is stationary. It is advisable to have an indicator on each cylinder, because it is an unpleasant business to shift one whilst hot, and the delicate mechanism may suffer from the awkwardness of the operation.

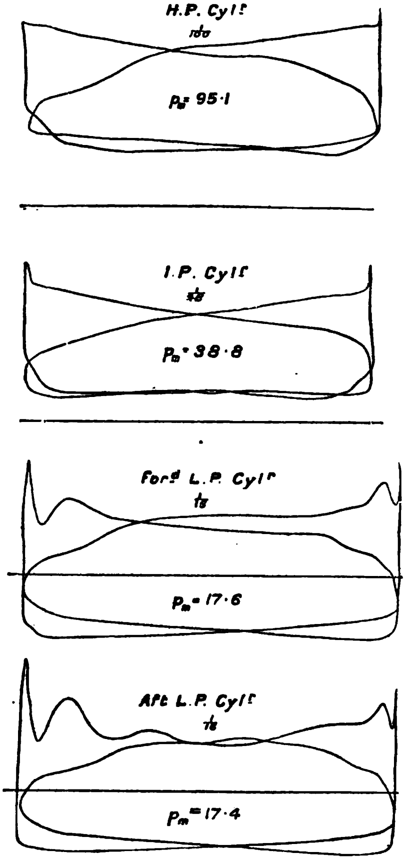

Fig. 6. (Total I.H.P. of each set of engines, 12,500.)

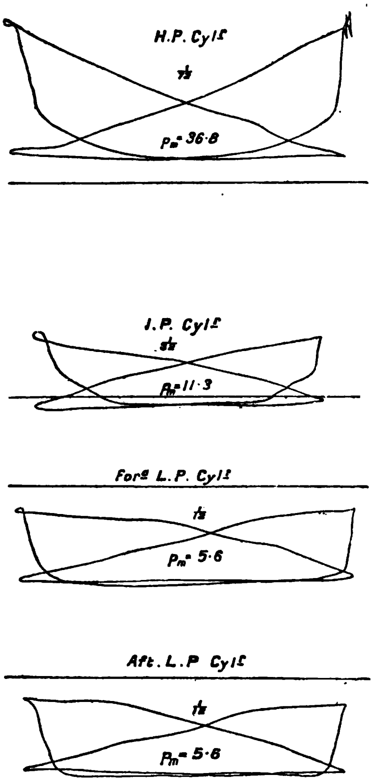

Fig. 7. (Total I.H.P. of each set of engines, 2,500.)

Accuracy of Diagrams.—Before placing the paper in position connect up the indicator to both ends of the cylinder through

water lodged in the
a considerable quan-
priming, and care is
sent in the indicator
The pipes leading to
meter, otherwise the
he resistance to the
mmon practice is not
herefore, it is rather
mal place, as though
gures arrived at. It
ssible, and it should,
ch can afterwards be

be recorded on each
of the card. It can
r more conveniently
s of a rubber stamp

f parallel lines, ten in
the diagram into nine
at each end. These
spheric line, which is
ut off and the atmo-
ssure at any point of
eam pressure on one
n the other side, and
B, the point A being
on the back pressure
oke. In practice the
iagram is obtained by
strip of paper. The
re for a stroke is re-
nth of the distance
rip of paper, and is
cale corresponding to
The mean effective
rn stroke is obtained
that for the cylinder
he mean pressure for

Planimeter.—A very
meter is made by the
Company, by the use
measurements become
uthor has found that

the mean pressure is very readily and accurately obtained by its use; and it is particularly suited for trial trips and full power runs, when two sets of diagrams have to be worked out each half hour. The adjustment of the instrument requires that the axis of the wheel should be parallel to the centre line of the swinging arm; and the edge of the L piece in the upper left-hand corner must be in the same straight line as the centre line of the slot in which the pivot piece, W, slides.

Steam Engine Efficiency.—The extensive subject of the thermal efficiency of steam engines is outside the proposed limits of this book. There are not many published reports of accurate trials made to determine the efficiency of marine engines. The best known are those made by a Research Committee of the Institute of Mechanical Engineers. The table on the next page is taken from the abstract made by Professor Hudson-Beare,* and is here given to afford a general idea of the efficiency of a marine engine.

Sir John Durston states (*Proc. Inst. Naval Architects*, April, 1897):—"In recent battleships, with 150 lbs. steam pressure at the engines, the mean coal consumption, at an average of 86·5 per cent. of the maximum power in four vessels, was 2·25 lbs. on trials of eight hours' duration, and at 51·3 per cent. the mean results from seven vessels gave 1·73 lbs. per indicated horse power per hour on trials of thirty hours' duration. In recent second-class cruisers, also with 150 lbs. steam pressure at the engines, the mean coal consumption in six vessels, at an average of 85·8 per cent. of maximum power, was 2·18 lbs. on eight hours' trial; and in nine vessels, at 51·1 per cent. of maximum power, it was 1·64 lbs. per indicated horse power per hour on thirty hours' trial." These engines are all of the triple-expansion type, and the steam is supplied by cylindrical, return-tube boilers. The results obtained on the trials of some ships with water-tube boilers are given in Table I., Chapter I., and compare favourably with the above figures.

S. S. "Inchmona."—The following particulars of the machinery and boilers of this ship are interesting. The makers, the Central Marine Engine Works Co., of Hartlepool, certify that the coal consumption is 1·15 lbs. per H.P. hour, and they have received a post delivery payment from the owners computed on that basis over a period of eighteen months' work at sea.

Type of Boilers.—Two cylindrical, multitubular, return-tube boilers, single-ended, of Mr. Mudd's standard type (see *Engineering*, 1898). Working pressure 255 lbs. per square inch (gauge). Serve tubes and Purves ribbed furnaces. A steam superheater, which can be disconnected if required, is fitted in the uptake.

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* *Proceedings of Inst. of Mech. Engineers*, 1894.

MARINE ENGINE TRIALS.

Steamer.	Cylinders.				Revolutions per minute.	Initial Pressure in H.-P. Cylinder.	Absolute Pressure in Condenser.	Total I.H.P.	Lbs. of Feed-water per I.H.P. per hour.	Heat per minute.		Engine Efficiency, per cent.	Coal Consumption, lbs. per I.H.P. per hour.
	Diameters in inches.			Stroke in inches.						Thermal Units taken up by Feed-water.	Thermal Units turned into work.		
	H.	Int.	Low.										
Two cylinder, compound—													
Fusi Yama, .	27·35	...	50·3	33·0	55·59	65·1	2·32	371	21·17	141,100	15,870	11·2	2·66
Colchester, . .	30·0	...	57·0	36·0	86·0 87·1	79·3 74·4	2·51	1022 957	21·73	788,700	84,630	10·7	2·90
Villo de Douvres,	50·12	...	97·12	72·0	36·82	104·0	4·72	2977	20·77	1,092,000	127,300	11·7	2·32
Triple, compound—													
Meteor, . .	29·37	44·03	70·12	47·94	71·78	149·3	2·73	1994	14·98	528,600	85,240	16·1	2·01
Iona, . . .	21·88	34·02	56·95	39·0	61·10	157·0	0·70	645	13·35	161,100	27,590	17·1	1·46

Method of Air Supply.—Ellis & Eaves' patent system of induced draught is used; the air heater tubes are placed above the steam superheater.

Auxiliary Machinery.—(*a*) The fan engine to supply the induced draught is one of Allen's compound engines.

(*b*) The steering engine makes on an average about 18,000 revolutions in the twenty-four hours.

(*c*) The electric light engines.

(*d*) The air pump, circulating, main feed, and bilge pumps are driven from the main engines.

(*e*) Weir's feed pumps. These pumps draw water from the float tank and deliver through the feed heaters to the boilers.

(*f*) An evaporator is fitted.

The above auxiliary machinery is supplied with steam from the main boilers, and their steam and coal expenditure is, therefore, included in the returns.

Feed Heating System.—The duty of the feed pumps on the main engine is to take the water from the air-pump hot well and deliver it through the Edmiston's feed-water filters, and through the exhaust feed heaters into the float tank of the Weir's feed pumps.

The feed-water receives its first increase of temperature from the exhaust steam passing from the L.P. cylinders to the condenser, thence it passes to a heater C, in which it receives heat from the delivery of the drains from the jackets and cylinders, No. 3 and the two Nos. 4. The feed-water then passes to the heater B, in which the drains from the jackets and steam chest of cylinder No. 2 supply heat; thence on to heater A, where the drains from the main steam pipe, and from the steam chest and jackets of the H.P. cylinder, supply sufficient heat to raise the temperature approximately to that of the boiler.

Dimensions of Cylinders.—Diameters—No. 1, 17 ins.; No. 2, 24 ins.; No. 3, 34 ins.; Nos. 4, 42 ins. and 42 ins. Stroke, 42 ins. Diameter of all piston-rods, 4½ ins.

Particulars of Jackets.—All the cylinders are completely steam-jacketed over the barrels, and top and bottom covers.

The jackets also serve as re-heaters to the steam exhausted from cylinders Nos. 1, 2, and 3.

Cylinder No. 1.—The jackets receive steam at full boiler pressure.

Cylinder No. 2.—The jackets receive steam through a reducing valve set at 150 lbs. per sq. in.

Cylinder No. 3 and the two L.P. cylinders receive jacket steam in common, through a reducing valve set at 90 lbs. per sq. in.

Efficiency of Certain Land Engines.—The following table is given by Professor Unwin in a paper published in the *Proceedings Inst. C.E.*, vol. cxxii., 1895 :—

RECENT ENGINE TESTS—LOWEST STEAM CONSUMPTION.

Kind of Engine.	I.H.P.	Boiler Pressure.	Piston Speed.	Lbs. of Steam per I.H.P.
Simple—		Lbs. per sq. in.		Per hour.
Sulzer, ...	284	87	372	18·4
Corliss, ...	137	62	...	17·5
Compound—				
Dujardin, . . .	548	90	570	13·46
Sulzer, ...	247	85	493	13·35
Wheelock, . . .	590	160	612	12·84
Leavitt, . . .	643	135	371	12·16
Bollinckx, . . .	305	91	479	12·19
Triple—				
Willans, . . .	30	170	384	12·74
Sulzer, ...	615	141	516	11·85
Allis, ...	574	120	203	11·68
Compound superheating—				
Schmidt, . . .	76	180	380	10·17

Economical Speeds.*—A very important point, especially in the engines of a warship, is economical working at reduced speeds. It is found that, at certain speeds below the fastest possible, a ship can be steamed an increased distance per ton of coal. If, however, the speed be reduced below a certain point, the distance covered per ton of coal decreases. The speed at which the change from increase to decrease takes place is termed the "most economical speed," and is of service when the chief consideration is to steam the greatest distance for a given quantity of coal. It is always a very low speed, and is rarely higher than that corresponding to 12 per cent. of the full forced draught I.H.P. The nature of this speed and the circumstances affecting it can best be examined by means of the accompanying diagram. The horizontal line $O_1 X_1$ (Fig. 9) represents the speed in knots, or, to a different scale, the revolutions per minute; lengths measured parallel to the vertical line $O_1 Y_1$ represent the consumption of coal per day, or, to a different scale, the consumption per hour for the main engines only. The curve

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* Abstract from a paper read at the U.S. Institution by Fleet Engineer Riley, R.N.

A B represents the consumption of coal per hour at any particular speed, for the main engines only.

Consequently, $\frac{O_1 M}{M F}$ is the distance steamed per ton of coal. From O_1 draw a tangent $O_1 E_1$ to the curve A B. Then the ratio $\frac{O_1 L}{L E_1} = \frac{O_1 N}{N G}$, and is constant for points on the straight line. The most economical speed is that represented by $O_1 L$, because, at the point E_1, the ratio $\frac{\text{speed}}{\text{expenditure}}$ is greatest. To prove that this is so, consider any other point F on the curve; and draw F G, G N parallel to $O_1 X$, $O_1 Y$ respectively.

Then, $\frac{O_1 L}{L E_1} = \frac{O_1 N}{N G}$ and is greater than $\frac{O_1 M}{M F}$.

Now plot $O_1 O_2$ to represent the consumption of coal for auxiliary purposes, per day or per hour according to the scale.

Then, taking total expenditure into account, the most economical speed is found at the point E_2; where $O_2 E_2$ is a tangent to the curve; the proof being exactly similar to that already given.

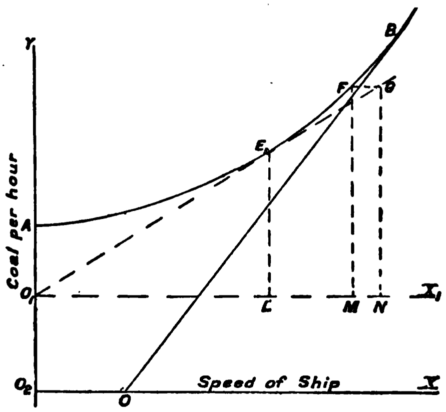

Fig. 9.—Speed and Coal Consumption Curve.

Next, as regards the effect of a following, or adverse, current. If the current be adverse, set off a distance $O_2 O$ to represent the speed of the current, or the equivalent number of revolutions, to the right of O_2. Draw a tangent O E. Then E is the point on the curve A B corresponding to the corrected most economical speed.

If the current is following, set off O_2O to the left of O_2 and draw a tangent from O as before.

Daily Reports to Chief Engineer.—The following reports should be made on a printed slip of paper to the chief engineer at 7.30 a.m. by the engineers of the morning watch:—

Maximum density attained during the night in each boiler.
Condition of boiler gauge glasses.
Condition of feed pumps.
Amount of water in reserve feed tanks.
Expenditure of make-up feed-water in previous twenty-four hours.
Amount of coal in bunkers in use.
Expenditure of coal in previous twenty-four hours.

Engine-room Registers.—The following information is recorded in the Engine-Room Registers in use in H.M. ships. They are designed for the records of one-quarter of a year.

Every Hour.—Coal used for making good distance. Steam pressure at engines and in boilers. Air pressure in stokeholds. Number of revolutions per minute of port and starboard engines. Vacuum in inches. Distance run.

Every Four Hours.—Density in all boilers by hydrometer. Temperatures of feed-water, of stokeholds, of engine-rooms, of coal bunkers, on deck, and of sea water. Direction and force of wind relative to ship. State of sea. Depth of water in bilges. Remarks by the engineer of each watch as to the working of machinery.

Daily.—Record of indicator diagrams, water made for boilers and for ship respectively. Amount of water in reserve feed tanks. Amount of feed-water received from shore. Number of boilers in use. Number of revolutions made. Expenditure of oil, for external lubrication, for internal lubrication, and for auxiliary engines. Result of litmus test of boiler water. Number of dynamos at work and period of working. Draught of ship forward and aft. Total distance run. Distance run for one ton of coal. Special remarks by chief engineer. Condition of boilers at midnight and noon. Number of hours fires were alight in steamboats. Description of coal used, quality of same. Expenditure of coal for making good distance logged, laying fires, banking fires and manœuvring, for steam launch, for culinary purposes, and warming ship or boilers, for distilling, for electric light, for other auxiliary purposes. Total expenditure of coal. Amount of coal remaining on board at midnight.

At the beginning of the register the following information is filled in:—

I.H.P. of engines; load on safety valves of ship's boilers, of auxiliary boiler, of steamboat's boilers. Draught of water aft when screw is just immersed. Pitch of screw. Quantity of coal which can be stowed in bunkers and elsewhere. Consumption of coal at $\frac{1}{5}$, $\frac{2}{5}$, $\frac{3}{5}$, $\frac{4}{5}$, and full power, and corresponding speeds of ship. Report of particulars of last full-power trial. Date when last undocked.

Quarterly Abstracts.—The following information is abstracted in suitable pages at the end of the register:—

Distance run under steam. Number of hours under way. Average speed. Distance run with 1 ton of coal. Maximum speed of running.

Expenditure of coal under the headings detailed above. Expenditure of oil as detailed above. Total water made for ship and boilers respectively. Amount of water received from shore for boilers.

Description of main engines; name of manufacturer; date of completion; date of last thorough repair; how long they will remain fit for service with such repairs as can be made by ship's artificers, or by those of an establishment on the station.

Examinations of main engines made in the quarter.

Examinations made and condition of the spare gear, and appropriations made of same.

Present defects of main engines and whether requiring the help of a shore establishment to make them good.

Similar abstract reports are made respecting the boilers, propellers, and auxiliary machinery. In addition, the friction tests of shafting are reported; the dates of the last drill tests and water tests of boilers, and the condition of the tubes, tube plates, and boilers generally, as regards scale.

Special Boiler Abstract for Information of the Admiralty.—An abstract of the working of the boilers for the quarter is made and the particulars as to the zinc slabs fitted are given. Any reduction of load on safety valves is recorded, accompanied by the date and reason of any such reduction. The maximum density attained during the quarter, and the average rate of rise of density. The quantity of feed-water which can be carried. The number of tons a day which can be distilled for make-up feed-water.

An abstract of the dates and matter of all correspondence, relative to the machinery, is kept in each current register. A page is provided at the end of the register for special remarks by the chief engineer of the ship, and the senior engineer officer on the station, as to the treatment and efficiency of the machinery.

Additional Information required in Register.—The following information may be recorded, besides that given in the register as printed:—

Time at which one coal bunker was emptied and another opened.

Quantity of ashes hoisted in each watch.

Quantity of water in reserve feed tanks at the end of each watch.

Amount of water distilled for ship's use and boilers respectively in each watch.

A report as to the condition of all gauge glasses and feed pumps at the end of each watch.

Notations to be Made in E.-R. Registers of H.M. Ships.*

When to be Made.	Art., *Steam Manual.*	Subject.
Daily	135	Men withdrawn; cause to be noted.
„	151	I.H.P. when under steam.
„	172	Engines moved.
„	224	Alkalinity of boilers.
„	264	Proportion of soda or lime used to weight of water in boilers which are in use.
„	495	Employment of steamboats.
„	245	Safety valve lifting gear worked each day.
„	766	Temperature of coal bunkers.
Weekly	245	Safety valves lifted off seatings every 10 days.
„	498	Sluice, drain, and ventilating valves, and W T. doors worked.
„	126	Telegraphs worked and condition noted.
„	223	Density of water in boilers when not steaming.
„	253	Adjustment of funnel guys (daily at sea).
Monthly	665	*In red ink.* Particulars of working second-class torpedo boats.
Quarterly	273, 256	Examination of boilers, slits clear, corrosion, zinc slabs, &c. Dates when last cleaned.
„	341	Condition of chocks and ties.
„	124	In each Register. Where spare gear removed from ship is left.
„	176	Condition of feed tanks and zinc slabs.
„	197	In each Register. Indicator diagrams at different grades of expansion.
„	327	Condition of zinc protectors of propeller shafts.
„	284	Preservation of boilers in reserve.
„	491	Tests of boats' boilers by water pressure.
„	122	Cleaning and examination of spare gear—dates.
„	519	Test of air-compressing machinery—report.
„	680	Occasions when steam was raised in steam-boats by steam from main boilers.
Frequently	125	Examination of auxiliary machinery.
„	173	Examination of all internal parts.
Occasionally	458	Consumption trials.
„	118	Defects made good by dockyard.
„	132, 133	Representations of engineer officer.
„	758	Quality of coal.
„	764	Number of hours bunker lids off.
„	769	Reasons if fuel-saving appliances are not used.
„	174	Condition of I.R. valves.
„	240	If boilers are used for trimming ship.
„	254	Time between drawing fires and emptying boilers.
„	227	Reason if cleaning of boilers is delayed.
„	308	Examination of boilers by chief engineer of ship after drill test.

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* As ordered by the *Steam Manual*, 1901.

NOTATIONS TO BE MADE IN E.-R. REGISTERS OF H.M. SHIPS (*Continued*).

When to be Made.	Art., *Steam Manual.*	Subject.
Occasionally	317	Reason when load on safety valve is reduced.
„	330	Friction test of propeller shafting when in dock.
„	655	When movable stays are removed.
„	127	Examination of steering gear by E.O.
„	222	Sudden rise of density in boiler.
„	226	Removal of water in boiler and density.
„	237	Reasons for not keeping boilers full up.
„	153	Indications of air pressure gauges.
„	129	Occasions when closed exhaust is in use.
„	196	Reasons for low rate of expansion.
„	461-474	Reports of trials to be attached.

STEAMING WATCH—BOILERS.

Visits to Stokehold.—The engineer of the watch should visit the stokehold frequently during the watch; he should find an opportunity of doing so at least once an hour. There is not so great a necessity for these visits when a junior engineer is employed in keeping watch in the stokehold, but this is rarely the case in H.M. Service. The following points should be attended to:—

1. **Water Level in the Boilers.**—Try all, or as many as possible, of the gauge glasses personally, and verify the readings by using the test cocks. Notice the water level in all the glasses, and the condition and motion of the water shown. If the motion of the water be unusually sluggish, it is probably due to the presence of dirt in the connections, or of an obstruction caused by the packing rings of the glass, and should be immediately investigated and remedied; the connecting cocks should be shut, the packing rings removed, and a wire inserted through the screwed holes provided for the purpose, in order to clear the bore up to the cock.

If the water in the boiler is clean, it is difficult to tell a full glass from an empty one by inspection; but if the top and bottom cocks be shut off, and the drain cock then opened, if the glass contains water it will run out. On connecting up, shut the drain, then open the lower cock gradually; if the water level in the boiler is above the orifice of the lower connection of the gauge glass, water will be seen to ascend in the glass till it reaches a full glass. Now open the top connection very slowly; if the water level in the glass is not again seen, the level is above full glass. The operation should be repeated for the sake of certainty. Instructions for the ordinary test of a gauge glass are given later.

2. **Condition of Fires.**—Look into the ashpits and see that the fires are uniformly bright along their length, and not dulled by clinkers at the back. See that the stokers are covering the fire-grate uniformly when supplying fresh fuel, and especially that the coal is not mainly supplied to the front of the grate, leaving the back bars thinly covered. See that the front dead-plates are kept clear of coal. If the boilers are double-ended, instruct the stokers not to fire opposite furnaces at the same time; also if two furnaces have a common combustion chamber, which is a frequent arrangement, they should never be fired at the same time. See that there is no accumulation of ashes in the ashpits, or any other obstruction to a free draught.

3. **Condition of Feed Pumps.**—Examine the feed pumps. Try the pet cocks to ascertain if there is a full regular stream of water. See that the nuts of the pump standards are secure. See that the glands are not leaking, and that the lubricators are properly filled. Try the auxiliary pumps.

4. **Coal Supply.**—Notice the quality of the coal issuing from the bunkers. See that the water-tight doors of bunkers not in use are properly closed. The sill of the door is sometimes fouled by coal dust, so that the door is imperfectly closed, in which position it is certainly not water tight.

5. **Density of Boiler Water.**—See the density of each boiler tested in the course of the watch (see *Steam Manual*, Art. 223). If a delay occurs before inserting the hydrometer in the water drawn off, the temperature will be too low, and the hydrometer will show too high a density. Hydrometers are generally graduated to test water at 200° F., though some are graduated for 100° F. To test the density of water drawn off from the feed tank, or from a cold boiler, it is necessary to heat the water to the temperature for which the hydrometer is calibrated. If a brass salinometer be used, it should be treated with great care, as, if dented, its displacement will be less, and it will register a false density; for this reason the salinometer should be compared from time to time with the readings given by a standard glass hydrometer. The scales of glass hydrometers sometimes slip out of position after a certain amount of use. The standard hydrometers should be tested from time to time in water of known density; for example, in water drawn from the sea, and properly heated. The water in the boilers should be tested once in twenty-four hours with litmus paper to detect any acidity.

Treatment of Ashes.—The engineer should see that ashes are properly damped and stacked in neat heaps in the stokeholds. Wet ashes should not be heaped against the boiler fronts, where they would cause corrosion of the front plates. Bulkheads, against which hot ashes have been stowed, have been known to warp. Ashes should be sent up in each watch, generally at six bells; they should not be allowed to accumulate to such an extent as to be an obstruction to the boiler attendants. In some ports it is against the harbour regulations to throw ashes overboard; in such a case they must be stowed in bags until the ash barge comes alongside.

Hydrometer Cocks.—Do not try to screw up leaky hydrometer cocks, test cocks, or other similar boiler mountings, whilst the boiler is under pressure. Brass is very brittle when hot, and if the end of the screwed plug is broken off the plug will be blown out, and most of the water in the boiler will be wasted. If such an accident happens, draw the fires without delay; watch the water level meanwhile; shut the stop valve on the boiler, and open the safety valves by the hand gear if the pressure rises above the working pressure. A sound plug should be inserted in the cock, as soon as possible, by enveloping the arms and hands in a wet sack and screening the rush of steam with a shovel. When the plug is secured, and the water level properly adjusted, the fires can be relaid and lit, and the boiler, being hot, will soon be ready to be re-connected with the engines.

Gauge Glasses.—Burst gauge glasses are frequently due to improper adjustment, whereby the free expansion, which should ensue when the glass is heated, is obstructed. Improper adjustment may be caused by the mountings at each end of the glass being out of line, or by unsuitable packing, and also through the packing glands being screwed up too tight. The following hints for fitting up a glass are given by Mr. John Moncrieff in *Engineering*, May 14, 1897.

"First, a good gauge glass must be used, which should not be too full for the size of the gland. Second, a good rubber washer should be used, protected by a ply of asbestos twine on both sides; and third, the glass should be movable by the finger and thumb after the glands have been tightened up. The steam end of the glass should be left a shade slacker than the water end."

It may be added that the ends of the glass should be accurately square with the length, and that the refitted glass should be warmed gradually. Also that the stuffing boxes should be thoroughly cleared out before refilling them. It does not follow that there is plenty of water in the boiler because there is plenty of water in the gauge glass, the passages may be choked. Empty gauge glasses are sometimes mistaken for full ones, and explosions have resulted therefrom. Hence it is of importance to verify the gauge glasses frequently. Gauge glasses are sometimes mounted on stand pipes, which latter are connected to the steam and water space through intermediate cocks. It is very necessary to keep both these cocks open continually, except when testing the cocks on the gauge glasses, at which time the method of double shutting off is necessary. Thus, to test the steam cock on the gauge glass, shut the water cock on the gauge glass and also the water cock on the stand pipe, and then blow out the glass. To test the water cock, shut the steam cock on the gauge, and also the steam cock on the stand pipe, and then blow through the glass.

The Admiralty have directed that where cocks exist on pipes connecting the gauge glass mounting to the boiler they are to be removed; the routine for testing a gauge glass is then as follows:—Shut the bottom cock, open the drain; if this blows properly the top cock is clear; shut the drain and the top cock, open the bottom cock and the drain; if the discharge is copious the bottom cock is clear; shut the drain, open the top cock, the bottom cock being still open, open the drain to empty the glass, and shut the drain; if the water level takes up its position smartly the gauge glass is correct.

It is not sufficient merely to blow through the gauge glass by opening the drain cock; the detailed test given above is urgently recommended.

Faulty Feed Pumps.—If a feed pump refuses to heave; first start the auxiliary feed pump to supply the boiler and so relieve anxiety about the water level. Then see that the valves on the steam and exhaust pipes are open, also that the suction and delivery valves on the pump are not shut. The difficulty may be caused by the presence of hot vapour in the suction pipe and valve chambers; cool the pump and pipe by throwing cold water over them from buckets. Tap the covers of the valve chambers to free the valves should they be sticking on their seatings; and tap the cover of the check valve on the boiler for the same reason. A troublesome pump may often be started by opening the pet cocks and leaving them open for some little time. It may be possible to get the pump into working order by using it to supply a cold boiler in which there is no pressure. If the pump heaves to the cold boiler, but not to the one in which there is pressure, it is probable that either the valves or the plunger rings are out of order, and the pump chamber must be overhauled. Examine the valves first, as they are more accessible than the plunger rings; if the fault is discovered in the condition of the valves it may not be necessary to undertake the longer job.

It sometimes happens that a pump refuses to heave against a pressure because the air in the pump chambers, &c., is not dislodged, but is compressed at each stroke of the plunger, and afterwards expands as the plunger recedes. It is for this reason that it is advisable to try the pump on a cold boiler, into which the air may be expelled.

Pumps are sometimes inefficient because the suction valves are too heavy, particularly if there is much "lift" from the suction tank.

Shortness of Water.—If a boiler is allowed to run short of water, the rate of combustion, or rather the ebullition of steam, must be immediately checked. If the water level is below the top-heating surface, the matter is serious. The following steps should be immediately taken:—Close the uptake dampers, draw the fires, shut down the boiler stop valve and regulate the steam pressure by the hand lifting gear on the safety valves. If the water is not below the level of the top-heating surfaces, turn on the main and auxiliary feed pumps. If there is reason to suppose that the water is below the level of the top-heating surface, there is cause to anticipate an explosion; for this reason the late Mr. Lavington Fletcher, of the Manchester Steam Users Association, recommended that a test cock should be fitted at the level of the top-heating surface to enable the engineer to determine whether it is safe to let the men stay to draw the fires and turn on the feed. He also recommended that the men should be withdrawn if the furnace crowns have commenced to bulge.

As an alternative to drawing the fires, they may be drenched, if so fitted, or deadened by a quantity of wet ashes, if at hand; also, it may be possible to dislodge the bearer bars by means of a heavy slice, so that the bars and fire are let down into the ash-pit. The author recommends that this latter evolution be first attempted when, on arrival in harbour, the order is received to "let fires out;" if the fires are heavy, it is a troublesome operation. It should be noticed that the level of the top of the heating surface is marked by an engraved brass plate fixed on the boiler front.

When connecting up an additional boiler the stop valve should be opened out with caution, to prevent damage from any possible accumulation of water in the steam pipe brought into use. The drain cocks on the boiler stop valve and on the steam pipe brought into use should be open for some time before the stop valve is opened out. Ease the boiler stop valve a quarter of a turn of the wheel when the pressure in the boiler is equal to that in those boilers already in use; about ten minutes later the boiler stop valve can be opened out to the required amount. In small ships with no auxiliary condenser, the air drawn off from a boiler, when it is first connected up, may affect the vacuum, and if any auxiliary engines are running on the vacuum, they may bring up in consequence of the reduction. A similar result may follow if the boilers be priming, the vacuum being affected by the heavier duty which falls on the air pumps.

Priming.*—"The amount of wetness of the steam depends on (1) the activity of ebullition, (2) the area of the water surface, (3) the volume of the steam space, (4) the position of the boiler stop valves, and (5) especially on the quality and condition of the feed-water. Mr. Thornycroft has found, by using a boiler with small glasses in the ends, that water which causes priming produces foam on boiling. Water which is very bad produces bubbles so durable as to remain a considerable time without bursting, and the steam space of a boiler may be entirely filled with them. The discharge then consists of foam, which becomes broken up on passage through the steam pipes."

With regard to the *first* cause, priming is likely to occur if the boilers are being forced beyond their capability; and again, if the speed of the engines be suddenly increased so that the steam pressure falls quicker than the temperature of the water in the boiler.

Secondly.—In a cylindrical boiler, a high water level usually means a decreased area of water surface, and consequently more violent ebullition of steam. It is for this reason that it is beneficial to adjust the water level at or about a quarter glass for full speed steaming.

Thirdly.—It is evident that a high water level produces a decreased steam space.

Fourthly.—The boiler stop valves should be so situated that they are in proximity to the driest steam. They are often fitted on a steam dome to remove them as far as possible from the water level. If an internal steam pipe is fitted, as is usual, the slots in it should be situated on the upper surface, and the steam pipe placed near the top of the boiler shell.

Fifthly.—This is perhaps the most common cause of priming. It is well known that certain fresh shore water is not suitable for high speed steaming; and boilers which have primed badly on trial have, after being washed out and refilled from a different source, shown no indications of priming. If the proportion of soda in the water is too high, priming is likely to result. It frequently happens that the boilers of steamboats prime after they have been washed out with soda water. Mr. Thornycroft's remarks on the formation of bubbles suggest that soapy impurities in the water are provocative of priming, and it may be remarked that the addition of soda to oily matter results in the formation of soap.

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* Prof. Unwin on "Determination of Wetness of Steam," *Proc. Inst. Mech. E.*, 1895.

The particular boilers which are priming may be recognised by the turbulent and broken condition of the column of water in the gauge glass.

Should the priming be continuous and common to all the boilers, it will be necessary to check the speed of the engines and also the rate of ebullition of steam. Close the dampers, ease the fans, pump more feed-water into the boilers, both to check the ebullition and also because the water level is rapidly lowered by priming. As a further remedy, if there is a reserve of feed-water, clean the surface of the water in the boiler by means of the surface blow-out. In the engine-room priming is indicated by the separator gauge glass filling up rapidly, and also by the loud knocking and reduction of speed which is the consequence of water in the cylinder clearance spaces. In such a case the separator, if one is fitted, must be blown out, the drains on the cylinders and slide valves must be opened, and, if necessary, the speed of the engines must be decreased to minimise the risk of damage.

If only one of a set of boilers be priming, the cause may be in the corresponding stop valve being opened too wide; and, in this connection, it may be remarked that the stop valves on remote boilers should be opened about half a turn wider than those on boilers nearer to the engines, because the longer steam pipe offers more resistance to the passage of the steam.

Stoking.*—The routine for stoking and cleaning fires is important as is explained in the following notes on "Combustion." A brief summary of the principal points to be observed is here given:—

The utmost regularity should be observed in stoking. Each fire should be fed in rotation according to a recognised system. No two fires on the same boiler should ever be fed at the same time. The doors should be opened smartly and closed directly the fire is fed. The coal should be placed ready in a position handy for each fire. The thickness of fuel on the bars should be maintained as constant as possible; about 4 ins. thick for easy steaming, up to 8 ins. thick with 2 ins. of air pressure. Fires should be cleaned in rotation. It is generally necessary to clean a fire after about twelve to sixteen hours steaming. The operation often consists of burning down the fire and then hauling everything out from the bars. It should never be necessary to clean two fires at the same time; a recognised routine should be laid down so that each fire is cleaned once in the twenty-four hours, or oftener if required by the rate of steaming, or by the quality of the coal. The quantity of clinker formed depends, when the coal is the same, on the quantity of coal burnt, and, therefore, fires require cleaning oftener at full speed than when steaming easily; also, some coals contain more incombustible matter than others.

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* See page 329.

If a ship is steaming over a period of some days it may be necessary to sweep the tubes. In the return tube type of boiler there is no difficulty in effecting this operation with brushes from the stokehold plates, or by means of a steam jet delivered from a nozzle attached to a portable hose led from an auxiliary steam pipe. During this operation the smoke-box doors must be opened, and the cold air which then rushes through the tubes is known to have an injurious effect on the boiler. Smoke-box doors should be opened as seldom as possible. Tubes are generally swept in the night watches. The "blacks" carried on deck are then cleaned up when the decks are washed down at 5.30 a.m. In the case of low cylindrical boilers, with continuous tubes, the combustion chamber must be cleared through the lower furnace, or through the ash tube if fitted, whenever tubes are swept.

Combustion.—In order to ensure perfect combustion of the fuel when the air supply is limited to that chemically necessary, it is necessary that the air should be supplied exactly as the fuel requires it, and every particle of the air must come in contact with the fuel. In the process of combustion of coal the first part consists in the evolution of the heavy hydrocarbon liquids, resin, tar, pitch, naphthalene, benzene, &c.; as the temperature rises, the lighter liquids are evolved, followed by the heavy gases as acetylene and olefiant gas. Afterwards the lighter marsh gas and later the hydrogen are liberated when the coke has attained a dull red heat. Weight for weight, hydrogen requires three times as much air as carbon for its combustion, and consequently, at first, a free supply of air is required, which may be diminished when the gases are all distilled. In practice, the bars, after firing, are covered with fresh fuel, which by its resistance to the passage of air will check the supply; also, the distillation of the gases absorbs heat from the fire, and the temperature is lowered, thereby lessening the draught. When all the hydrogen gas has been evolved there remains a fire of glowing coke, with air channels forced through it, and the draught is consequently much quicker, and increases till the next firing takes place. It is seen that the air is supplied in exactly the opposite way to that required by the gases formed, and for this reason the air supply must be greater than that chemically necessary. In practice with chimney draught the supply of air must be twice that chemically necessary, or about 24 lbs. per lb. of fuel; when forced draught is used the supply of air is forced more uniformly through the fires, and about 18 lbs. per lb. of fuel gives the best result.

The quantity of air supplied, and the method of supplying it, affect the performance of the boiler in two ways:—

If the air be rapidly supplied under pressure by fans, the combustion is more rapid and more coal is burnt per square foot of grate per hour. The velocity of the gases through the boiler is great and there is little time for the heat to be transmitted through the heating surfaces. Consequently, the temperature of the funnel gases is high, and the loss occasioned by the discharge of the hot gases from the funnel may be great. The output of the boiler is, therefore, increased at the expense of economy.

If the air be supplied more slowly, as by natural draught, the combustion is comparatively slow, and perhaps incomplete, but the velocity of the gases through the boiler is slow enough to allow a larger proportion of heat to be transmitted through the heating surfaces, the funnel waste is reduced, and the efficiency of the boilers is increased. For this reason, boilers attain the most economical result when working below full power, and it is advisable, when cruising, to determine the most economical power of a boiler, and use the knowledge so gained to determine the best number of boilers to be lit up at different speeds.

If the supply of air be insufficient, the loss of heat, due to incomplete combustion of the hydrocarbon gases, may be as much as 40 per cent.; and if the coke be burnt to carbonic oxide only, a further loss of 40 per cent. will result.

The quantity of air used can be checked by analysing the products of combustion; the method can be best explained by an example:—

S.S. "Iona." Experiment by Committee of Inst. of Mech. Engineers, 1893. Per cent. analysis of coal used:—

$C=82{\cdot}34$; $H=5{\cdot}47$; $O=6{\cdot}96$; calorific value, 14,830 B.T.U.

Per cent. analysis of chimney gases, by weight:—

$CO_2=12{\cdot}12$; $O=12{\cdot}01$; $CO={\cdot}00$; $N=75{\cdot}8$.

Then

C in products was $\frac{12}{44} \times 12{\cdot}12 + \frac{12}{28} \times {\cdot}00 = 3{\cdot}305$ per cent.

N in products was . . . . . $75{\cdot}87$ per cent.

$$\therefore \quad \text{N supplied per lb. of C} = \frac{75{\cdot}87}{3{\cdot}305} = 22{\cdot}95 \text{ lbs.}$$

$$\therefore \quad \text{N supplied per lb. of coal} = 22{\cdot}95 \times {\cdot}8234 = 18{\cdot}9 \text{ lbs.}$$

$$\therefore \quad \text{Air supplied per lb. of coal} = \frac{18{\cdot}9 \times 100}{77} = 24{\cdot}5 \text{ lbs.}$$

It is necessary to be careful to obtain average samples of the gas and to make repeated tests at intervals.

Dasymeter.—Professor Unwin has described a form of balance called the Dasymeter;* an instrument which automatically records the per cent. of CO_2 present in the funnel gases. When adjusted it is as easy to read as a Bourdon pressure gauge, and it will give a continuous record over twenty-four hours. The stoker is instructed to adjust his draught plates so that the per cent. of CO_2 is invariably about 12 per cent., when, as seen in the above example, the supply of air is about 24 lbs. per lb. of fuel. It is reported that a saving of fuel of about 20 per cent. is effected by its use. The instrument consists of a balance—on one arm is carried a globe of large displacement, on the other a brass weight. The instrument is contained in a case placed in the funnel. Any alteration of the density of the funnel gases disturbs the balance, and its motion is registered by a pencil which traces a curve on a revolving sheet of paper. The per cent. of CO_2 can be read, at any instant, on a graduated scale. There is a mercurial compensator which regulates the instrument for different temperatures and barometric pressures.

The following is the record of one set of experiments made with it:—

Duration of Trial. Hours.	Coal Burnt per 1,000 lbs. of Steam.	Steam Pressure (Atmospheres).	Per cent. of CO_2 by Dasymeter.	Chimney Loss. Per cent.
10	152·6	5·88	6·8	33
10	125·0	7·28	13·1	13

Saving effected 18 per cent., same coal used, feed-water at the same temperature.

Automatic Regulation of Air Supply.—A large number of such arrangements have been tried but generally have been found too delicate for marine purposes. Generally speaking, in H.M. vessels the only means of supplying air above the grate is by means of small holes in the furnace front, or by jets of compressed air from nozzles. In the Belleville boilers a small proportion of the total air supply is pumped into the furnace above the grate at a pressure of from 5 to 18 lbs. per sq. inch. The supply pipe runs across the front of the fire, and has a number of nozzles tapering from $\frac{3}{16}$ inch to $\frac{1}{8}$ inch. If the air pressure falls low the funnels commence to flame. The air is delivered at a considerable velocity, and the effect is to thoroughly mix the unconsumed gas with uncombined air, and so promote combustion ; hence the name "gas mixer."

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* *Proceedings of Inst. of Civil Engineers*, vol. cxxii.

A similar arrangement is fitted in the Thornycroft water-tube boiler, the air-compressing plant being, in this case, driven from the main engines.

It is necessary to carefully distinguish between the absence of smoke and perfect combustion; the smoke may disappear, but if the carbon combines to form carbonic oxide, the combustion will be far from perfect.

The only way to ensure perfect combustion is to supply the fuel and air in a continuous stream. This is effected by apparatus for mechanical stoking in land boilers, but no system has been generally adopted at sea. During the trials of the Belleville boilers of H.M.S. "Powerful" and "Terrible," the thickness of the fires was kept as uniformly as possible at 6 ins., and a sprinkling of coal was supplied as quickly as possible. The instructions issued were, "Fire lightly, fire quickly, fire often." Dials were placed around clocks in the stokeholds showing at what intervals (of three to four minutes) each particular furnace was to be fired. It has been found beneficial with water-tube boilers to insist on uniform stoking, which ought to approximate to the regular supply attained by the use of automatic machinery. The fans supplying the air to the furnaces must be run at a regular speed. It often happens that the fans are used to cloak faulty stoking; the fires having been heavily fired the speed of the fans is temporarily increased to force the air through the fuel, whilst when the fires are subsequently burnt thin the speed is diminished; this practice should be corrected and the system of quick regular stoking established.

Coals.—Professor Unwin * states that the better kinds of coal do not differ much in absolute calorific value. The calorific value of good coal is given by D. K. Clerk as from $12\frac{1}{2}$ to $13\frac{1}{4}$ lbs. of steam, evaporated from water at 212° F., per lb. of coal. When coal is burnt in boiler furnaces its calorific performance varies, because the more bituminous coal requires a greater air supply for tolerably complete combustion. The greater excess of air involves greater chimney wastes. Sir William Anderson* says that a different class of boiler is required for a hydrocarbon fuel, such as North Country coal and petroleum, as distinguished from anthracite or coke. In the first case, large and long flues are necessary, because combustion continues far along the flues, and the radiant power of the smoke is high.†

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* *Proceedings of the Inst. C.E.*, vol. cxxii.

Funnel Gases are principally diathermous, except olefiant gas, water vapour, and CO_2 to a certain extent; so that, in a furnace, little heat is radiated from the hot gases; the furnace plates receive the heat they transmit by conduction of the fire-bars and radiation from the glowing fuel and smoke particles. Brick arches and tiles in a furnace absorb much of the radiant heat, and ensure a temperature sufficiently high for the combustion of the gases. The gases in the furnace and combustion chamber act by heating the solid particles of carbon or soot which radiate the heat. For this reason it is not found economical to arrange a non-tubular boiler so that the combustion is perfect; the products deprived of the particles of carbon or smoke are deficient in radiant power and carry much of their heat to the funnel.

The following table of boiler trials is given by Professor Unwin, *Proc. Inst. C.E.*, vol. cxxii. :—

Boiler Trials.

Type.	Ratio of Grate to Heating Surface.	Coal burnt per sq. foot of Grate per hour.	Evaporation in lbs. of Water from and at 212° per lb. of Coal.	Coal.
Cornish,	...	7·2	11·9	Welsh
Lancashire,	1 : 36	22·9	11·2	Lancashire
Galloway,	1 : 24	8·5	11·6	Anthracite
Portable,	1 : 69	12·8	11·8	Welsh
Tubular,	1 : 46	10·8	11·9	Anthracite
Babcock,	1 : 38	8·9	11·8	,,
Marine,	1 : 34	22·4	12·9	Welsh
,,	1 : 50	25·5	12·5	Lancashire
Thornycroft,	1 : 70	7·7	13·4	Welsh
,,	1 : 61	18·6	12·5	,,

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* "Heat in its Mechanical Applications," *Proceedings Inst. C. E.*, session 1883-84.

† The furnaces of a Scotch boiler can be adapted to burn North Country coal without smoke by fitting a special door to admit more air above the fire, by lessening the area through the furnace throat, and, in particular, by increasing the area of white-hot firebrick over which the furnace gases must pass.

Fire-bars.—The life of a fire-bar depends very much on the skill of the boiler attendants. If a particular fire be too heavily charged with coal the draught of air is reduced, because the supply naturally takes the easier passage through a thinner fire; in consequence the fire-bars may become overheated, and cases have occurred where the white-hot fire-bars have collapsed, and let the heavy load drop into the ashpit. The life of fire-bars may often be prolonged by increasing the width of the air space between them. Fire-bars should have the necessary clearance for their longitudinal expansion, otherwise they will be warped when heated. Transverse air holes are bored through deep fire-bars in order both to lighten them and to provide more cooling surface.

Hollow fire-bars are used in some boilers. In Caddy's arrangement, air circulates through the bars and tends to keep them cool; it is claimed that the additional air so supplied into the combustion chamber increases the efficiency of the boiler. Thornycroft has fitted some boilers with hollow fire-bars, through which the actual feed-water circulates.

If the engines are suddenly stopped when steaming hard with thick fires, the fire-bars run a risk of overheating, since the dampers must be closed to check the combustion, and consequently the cooling current of air is shut off. This accident occurred in two boilers out of four on the steam trials of one of H.M. ships.

Furnace bars may be replaced whilst steaming, the dampers being closed and the fire cleared from the vacant space. Water troughs provided in the ashpits of a boiler, and kept well supplied with water, decrease the risk of burning the fire-bars.

Overheating of funnels or uptakes is caused by the imperfect combustion of the gases in the combustion chamber, and may be remedied by increasing the air supply above the fires; a temporary remedy is to slightly open the furnace door. It is evident that the thickness of the fires must be reduced if the overheating is continuous.

CHAPTER VI.

SHUTTING OFF STEAM.

On Stopping Unexpectedly or Waiting under Steam.—If the engines are stopped unexpectedly the steam pressure will tend to rise quickly. Every precaution should be taken to prevent the loss of fresh water caused by the safety valves lifting.

Telegraph to the stokehold; the fans should be stopped; all ashpit dampers should be closed and also, if they are fitted, the dampers in the uptakes. These latter are important, and will greatly check the rate of combustion and the consequent rate of ebullition of steam. Check the supply of air to the stokehold, if necessary, by closing the dampers in the air-trunks from the cowls. If the water levels are sufficiently low, pump water into the boilers.

Open all drains on the cylinders and valves to keep the engines and steam pipes clear of condensed water, which, if allowed to accumulate, will cause delay in starting. These drains should not be opened to the bilge, as feed-water would thus be wasted. Ease the silent blow-off valves and open them out gradually if such action is rendered necessary by the rise of the steam pressure. Put a pump on the condenser to keep it pumped out, and so guard against a glut of water in the air pump on starting. If this precaution be neglected it may happen that the seating of the foot or head valves and the pump bucket will be smashed up by the pressure due to the inertia of the accumulated water.

Stop all internal water supplies to the bearings.

Watch and regulate the steam-jacket pressures, which will tend to rise.

Watch the pressure in the receivers, and open out the receiver relief valve if the pressure approaches the load on the receiver safety valve.

Keep the reversing engine drained, and ready for use immediately orders are telegraphed to start the engines. Run the link over from time to time.

Keep the attendants clear of the engines for fear the latter are fidgetty.

If the steam pressure rise, start the evaporators to use up the steam developed, for the same purpose start the bilge pumps to pump out the crank pits and bilges.

After re-starting, be careful to carry out the necessary reversals of the above operations—*e.g.*, do not leave the silent blow-off valves open after the steam is reduced to working pressure.

On Entering Harbour.—When nearing the port the fires should be burnt light, and a good look-out set on deck to report the various stages of entering harbour. If the fires are properly burnt down, there will be no difficulty in keeping down the steam pressure, and also no unnecessary waste of fuel. About half an hour's warning is generally sufficient for the boiler attendants.

Have the tell-tales to the bridge put in gear.

Have steam put on the capstan engine to warm it up; ship the deck pedestal for the steam valve; try the engine, and let the attendants stand by to work it when required.

Get rid of all ashes before entering port.

Shut off the water service when the engines are put to slow, work all the water out of the bearings, and give them an extra supply of oil from the feeder, withdrawing the worsteds temporarily. This procedure will prevent the journals rusting in port.

Pump out as much water as possible from the main drain and bilges before the ship gets into harbour.

There will generally be an engineer officer in each engine-room, besides the chief, to see that all orders for working engines are promptly carried out.

Shutting off Steam Pressure.*—Immediately the order "Finished with the Engines" is received, shut the master, pass, and jacket valves, but be careful not to block the connection between the silent blow-off valves and the boilers. The silent blow-off valve should be fitted on the auxiliary steam pipe.

Get rid of the steam in the engines and engine-room main steam pipe by running the reversing engine round till it stops for want of steam.

Open the receiver relief valves, and all drains on the engines.

Shut steam off the reversing engine and steering engine.

When there is no steam left in the engine-room main steam pipes, put in the turning gear; the men may then be allowed to work on the engines.

Wipe down all rods and shafting with cotton waste, and oil all bright parts to prevent rusting. The engines should be wiped down whilst warm.

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* Similar orders to those here given are of great benefit if posted in the engine-room.

Pump out the bilges. Clean and dry up crank pits, bilges, and engine-room plates with oakum. The oakum is picked from old rope by the men at odd times, and saves the expenditure of cotton waste. Disinfectants are supplied for use in the bilges; if the latter are kept clean the disinfectants will rarely be required.

Take out worsteds two hours after stopping, empty all lubricators, and filter and separate the oil so recovered.

Pump all boilers to working height.

Clean the fires in the boilers to be used for auxiliary purposes before the fires are low in those to be shut off.

Tighten the stern glands till the drip ceases.

Place gaskets around the bearings, and replace covers to prevent dirt entering the bearings or lubricators whilst in port.

The main circulating engines may generally be stopped about two hours after shutting steam off the main engines. Close the main inlet and outlet valves after stopping the circulating engines, and, if the stay in harbour is to be for some days, drain the main condenser and air pumps.

A separate order should be received before letting fires die out, as the ship may have to shift billet after arrival.

Letting Fires Die Out.—On receiving the order from the chief to let certain fires die out, allow the fires to burn themselves out, then draw the ashes and clinkers from the grates. When the steam pressure in the boilers is well below working pressure, and dropping, the boiler and bulkhead stop valves may be closed in detail, the operations being personally supervised by the engineer. The routine for letting fires out should be devised with the view of letting the boilers cool gradually.

On the Day after Arrival.—Sweep tubes in the morning watch. Clean the furnaces out thoroughly, and get up soot and ashes. Get the coal dust and ashes out of the stokehold bilges, and dry up the bilges. Much of the coal so recovered can be dried and used in the boilers for auxiliary purposes.

Overhaul the firebars, and replace the burnt ones as necessary; straighten bars and bearers.

Examine the brick bridges, and repair them as required.

Examine the tube ends, and ascertain if any have leaked; replace tube ferrules as required, and roll leaky tubes.

Banking Fires.—If a ship enters harbour for a stay of less than twenty-four hours, and, in certain circumstances, when she is awaiting orders, or lying in an unsafe anchorage, the fires are banked. The routine is to burn the fires thin, and let the steam pressure drop to rather less than half the working pressure; the boiler is pumped up to a good half glass. The clinker is then withdrawn from the remaining fire, which is afterwards pushed to the back of the furnace, and fresh coal is added until the fuel nearly touches the furnace crown, all of it being at the back of the grate near the bridge. All ashpit dampers are then shut, and the steam pressure is maintained with a small expenditure of fuel. The boiler stop valves may be shut or not, according to circumstances, but no steam must be withdrawn from the boiler, and the boiler attendant must see that the water level remains within ordinary limits.

If the boiler is urgently required, it can be prepared in about thirty minutes by spreading the banked fuel and firing up. The fire is sometimes banked at the front end of the grate; but in such a case cold air will pass through the ashpit and the uncovered back portion of the grate, and may cause leakage in the boiler from unequal local contraction.

CHAPTER VII.

HARBOUR DUTIES AND WATCHES.

General Condition of Machinery.—The first principle observed by engineers in this connection is to maintain the machinery under their care in such a condition that it is ready for use whenever required. The conditions of service at sea are such that machinery may be required at unexpected times, consequently, whenever important machinery is taken in hand for an overhaul or repair, the work must often be carried on, irrespective of the time of day, until the machinery is again ready for use, or can be made so within the usual interval between the reception of an order and its time of execution. It will be understood that considerable forethought and precaution are required to enable the necessary refitting work of a larger kind to be carried out. The ordinary working hours in harbour of engineers afloat are not unduly long, but the principle referred to in the preceding remarks sometimes taxes the staff considerably, and calls for prolonged exertion.

The method of carrying out the particular repairs required by the machinery will be found described in the chapter on "Adjustments," the subject at present being the upkeep of machinery which is in use or in working condition.

EXAMPLE OF A SET OF STANDING ORDERS FOR HARBOUR DUTY.*

In the following notes the letters P.O. stand for petty officer.

A responsible P.O. will, as far as possible, work all cocks and valves in the engine-room and screw alley every Monday morning, and report their condition to the senior engineer or engineer of the day. He must take care that he does not entirely close any cock or valve which it is necessary to keep open for any particular engine, nor open any cock or valve which would endanger the machinery or the men in its neighbourhood.

The boilermaker is to test the water in each boiler every Monday morning with litmus paper,† and is also to take the density, and a report is to be sent to the engineer's office before noon. He is also to report any increase of density, and is to satisfy himself that boilers supposed to be standing full up are really in that condition.

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* A similar set of orders will be of benefit if posted on a notice board in the engine-room.

† The following tests are much more reliable and sensitive than the litmus paper test:—(1) Add one or two drops of methyl orange to a sample of the water, the colour will turn yellow if alkaline, or a decided pink if acid. (2) Add one or two drops of phenol phthaline to another sample, the colour will turn whitish if acid, or magenta if alkaline.

In the case of boilers opened out for cleaning, particular care is to be taken by the boilermaker that no men are inside the boiler while he is trying the mountings. Stop valves, &c., of boilers opened out for cleaning or examination, are to be shut and securely lashed whilst the work is in progress.

The chief stoker of the engine-room, or other responsible person, will pass the word, at all times of ceasing work, for "in lights."

Tubes in auxiliary boilers are to be swept on Sunday, Tuesday, and Thursday nights between the hours of 10 p.m. and 6 a.m.

Fires are to be cleaned every morning watch, and, in warships, are to be built up on Mondays and Fridays, to be ready for the routine drills.

Ashes are to be neatly stowed in the stokeholds in bags, and are not to be stacked in heaps against the bulkheads or boiler fronts.

The chief stoker of the stokehold is to communicate with the chief stoker of the upper deck party when the time appointed for getting rid of ashes arrives; this occurs generally on turning to in the morning. The P.O.'s of the deck party are responsible that the ashes are hoisted up and discharged overboard. No ashes are hoisted up on Sundays in warships, because the decks are then kept ready for inspection.

Coals for the galley and also the bogies required for warming ship, are to be hoisted at the regular appointed times, generally about three times a week. These bogies are placed in a furnace of a boiler not in use to burn clear, and are thus made use of to dry the uptakes and combustion chambers. One fire engine is to pump continuously through the seamen's head; a constant pressure (as arranged) is to be maintained.

The main drain, or bilges, are only to be pumped out in the middle watch, or at other times as ordered. If occasion arises unexpectedly, a communication is to be made to the quartermaster on deck, and permission obtained, in order that boats alongside may not be fouled by the greasy water. After being used for pumping out bilges, the pump should draw from and discharge to the sea, before the discharge is diverted into the fire main, to wash the pipes out with clean water.

The ventilating fans are to be started and stopped according to the orders for ventilating the ship applicable to the time of year and climate.

It is to be clearly understood that, as a rule, all sluice and drain valves throughout the ship are to be kept closed and only opened when required for immediate use, after which they are to be closed. The same order applies to the water-tight doors of coal bunkers. Only bunkers in use are to be open. It should be a rule that, after working hours, only those water-tight doors required for traffic should be left open; as many as possible should be closed throughout the night, and the engineer officer should, when going rounds, see that the orders respecting water-tight doors have been carried out.

A fitter E.R.A. is to examine carefully the feed pumps in use on "turning to," and is to report their condition to the senior engineer.

Each engineer officer will inspect his own part of the ship before 8 a.m. on Sundays; preferably in time to have small faults rectified before the men leave; he will afterwards report his department ready for inspection to the chief engineer.

On Saturday forenoons the storekeeper is to give the blacksmith the tools which require repairing. The blacksmith will also repair any spanners and other implements which may have been damaged in the week.

All tools and hand lamps borrowed from the storekeeper are to be returned each evening. The storekeeper will keep a list of the issued tools on a slate, and will report to the E.O. of the day when everything is returned, or if any tools or lamps are missing. No hand lamps whatever are to be retained by day men in any of the departments. Those lamps required by watch-keepers are to be carefully attended to, and the watch-keepers are responsible for their safe custody; they are to guard against fire caused by sparks blown from the lamps, or from overheating of woodwork due to the proximity of the lamp flame.

No clothes or boots are to be left lying about the department, nor are they to be placed in stow holes.

The men will put their change of clothes, when they begin and leave off work, in the proper lockers provided.

No clothes are to be left hanging to dry during working hours, unless special permission is obtained from the senior engineer.

On no account is anything inflammable to be placed on the tops, or at the backs, of the boilers. Proper drying lines may be provided which are to be used only at the appointed hours. These lines are not to be placed inside the boiler casing.

On entering the engine-room department the men will put on their working boots, and on leaving they will remove them, in order not to soil the decks with dirty boot marks.

Men, when at work below, are to be properly dressed in clothes of uniform pattern.

All main and auxiliary machinery not in use is to be moved daily by the hand gear.

The main engines, when not in use, should be oiled at least once a week.

ORDERS FOR THE PETTY OFFICER IN CHARGE OF A SUB-DEPARTMENT ON DAY DUTY.

He is responsible that no cocks or valves in his department are interfered with by unauthorised persons; that drain valves are left as directed; that all glands of pumps and small cocks and valves are efficiently packed; that the men carry out their work as directed; and that the department is always in a proper state of order. He is responsible for the return of naked lights and tools at clearing up time; and that spanners, &c., are replaced in the proper racks; also that the department is left cleaned up ready for inspection by the proper officer. Before leaving the department he is to see the water-tight doors closed as ordered.

He is to supervise all cleaning work, and is to make sure that bearings are properly protected from dust and dirt by canvas, or more permanent, covers. He is to see that no oily waste and other *débris* is thrown about or allowed to accumulate. Such dangerous combustible substances are to be immediately collected in iron pails and sent into the stokehold to be burnt in a boiler furnace.

He is to report defects, as observed or made, to the senior engineer, or to the proper officer of his department.

He is to see that all the machinery in his department is properly moved each day, and that it is kept in a proper state of cleanliness and preservation.

ORDERS FOR THE PETTY OFFICER IN CHARGE OF BOILERS IN USE FOR AUXILIARY PURPOSES.

He is to maintain a constant steam pressure.

He is to maintain a constant water level.

He is to economise the consumption of coal by careful, smart, and regular stoking.

He is to exercise proper supervision and control of the stokers in his watch.

He is to try the test cocks of all water gauges about once an hour.

He is to pay proper attention to the lubrication and working of the feed pumps.

He is to carry out the special instructions given him in the Harbour Routine Orders.

He is to fill up the proper columns in the engine-room register:—The quantity of coal used each hour, the water in the reserve feed tanks, the steam pressure, densities of boiler and feed tank, temperatures of stokehold and coal bunkers in use, and particulars of the auxiliary machinery in use are to be logged in the Engine-Room Register. The P.O. will also log any slight defect observed in the machinery, and draw the attention of his relief to the defect. He will immediately report any serious defect to the engineer officer of the day, or other engineer officer more readily available. The latter should take steps to inform the chief and senior engineers of the nature of the emergency as soon as possible.

The P.O. in charge of boilers should lose no time in summoning the nearest competent person to assist him in case of a difficulty arising which he does not thoroughly understand. Many accidents may thus be averted by prompt action.

In order to economise the consumption of fuel in the night watches, when the load on the auxiliary machinery is light, one wing fire in each boiler may be used for burning good ashes.

Precautions for Starting additional Auxiliary Engines.—In order to assist the P.O. in charge of the boiler in use for auxiliary purposes, proper notice should always be sent to him when extra machinery is to be started, in order that he may brighten and thicken his fires and so supply a proper amount of steam. The notice should be sent half an hour before the auxiliary engines are required, for it should be remembered that a certain amount of steam is required to warm up large auxiliary engines.

Consequent on an increased number of auxiliary engines being used, the auxiliary condenser will require attention, and the quantity of circulating water must be increased to prevent overheating; also, the speed of the air pump must be increased and regulated. The engineer officer on duty may be able to supply the steam, needed by an unexpected demand for a particular auxiliary engine, by stopping some less important engine until the fires have burnt up sufficiently. The particular course to be followed will require a little judgment, and should be referred to a senior officer if time permits; and in any case a report of the circumstance must be made, and also logged in the register.

As an instance, suppose the boat hoist engines are required for a period of perhaps twenty minutes, the evaporators might be stopped during that period; but the operation requires care and the personal supervision of an engineer in order to prevent priming on restarting the evaporators.

When large auxiliary engines are started a great quantity of water formed by condensed steam is circulated through the auxiliary exhaust pipes. This water often finds its way into the cylinders of engines already at work, and heavy knocking may occur. In such a case the engines affected must be eased, and the drain cocks on the cylinders and slides opened to get rid of the water. Fast running dynamo engines are usually most affected in such a case, and the watch-keeper on them should receive proper warning.

On Starting Auxiliary Engines.—The steam and exhaust pipes connected up should be drained as thoroughly as possible. The routine to be carried out is very similar to that required when warming up the main engines. The cylinders and slides should be warmed very gradually by the admission of a small quantity of steam; all drains should remain open till they blow freely; the lubricators should be attended to; and, finally, the engine should be turned by the hand gear through a dozen revolutions before the full steam pressure is admitted. The engine should be started very slowly; great strains may be set up in the cylinders by want of clearance, or in the exhaust pipes by the momentum of the water collected, if the steam be admitted too quickly. A very little steam should be admitted by easing the valve, and the engine turned by hand until it starts automatically. If an auxiliary engine refuse to start after this treatment, the reason may often be found in the fact that some exhaust valve has not been opened, or, more rarely, an essential steam valve.

Similarly, on starting pumps, ascertain personally that all necessary valves are open. A pump is often started with the delivery valve closed; should the pump be fitted with a pressure gauge, as fire engines are, the fact will become apparent. Such accidents should on no account be permitted to occur, and are the result of thoughtlessness and want of proper supervision. A young officer should remember that his subordinates are relieved of responsibility by his presence, and should himself take the proper precautions before putting steam on the engines.

SUMMARY OF WEEKLY HARBOUR ROUTINE IN A WARSHIP.

Monday.—Work all sluice and drain valves throughout department. Test water in boilers by litmus paper, and take densities. Work all boiler mountings. A party of stokers is required for the deck evolution carried out in the morning.

Tuesday.—Remove lids of coal bunkers for ventilation from 6 a.m. till noon.

N.B.—Bunker lids should never be off whilst decks are being washed.

Wednesday.—Clean bilges and main drain tanks.

Thursday.—Examine and work all water-tight doors and oil the screws. Work all automatic valves in ventilation trunks. "Make and mend" in afternoon.

Friday.—General quarters in forenoon at 9.30; work the branch-flooding valves to the magazines as convenient.

Saturday.—Clean up all departments in afternoon, ready for inspection on Sunday. Fire quarters at 7.30 a.m. on last Saturday in the month. Repair all tools for the department.

Sunday.—Clean up department till 8.30 a.m. Attend divisions on deck at 9.30 a.m., and church afterwards.

Daily.—Turn main engines and all auxiliary engines and pumps. Work regulating valves, safety valves, and engine-room telegraphs. Take temperature of all coal bunkers twice daily.

Economy of Coal in Harbour.—It is now considered of the greatest importance that the steam required for the auxiliary engines should be confined to as short and compact a length of steam pipes as possible. The coal expenditure required to keep an extensive range of steam pipes warm and drained may even greatly exceed that actually required by the auxiliary engines in use.

CHAPTER VIII.

REPAIRS AND ADJUSTMENTS OF MACHINERY.

On arrival of the ship in harbour the department must be cleaned up, the machinery oiled down to prevent rusting, and the tubes and furnaces cleaned from dirt, as detailed elsewhere. At the same time that the hands are employed on these duties, the skilled mechanics will be engaged in refitting and adjusting the bearings, remaking joints, and carrying out those repairs which can be undertaken with due regard to the length of time the ship is likely to stay in harbour.

Estimate of Time Required.—Whilst it would be unwise to undertake a job for which there is obviously insufficient time, yet the engineer is accustomed to make special calls upon the endurance of his staff, and to arrange that important repairs shall be carried out by relief parties, working turn and turn about until the job is finished. Whenever an estimate of the time required for an examination is given in the following remarks, it is to be assumed that no untoward circumstance occurs.

Before taking any machinery to pieces see that the parts are plainly marked, so that there will be no difficulty or delay in re-erecting.

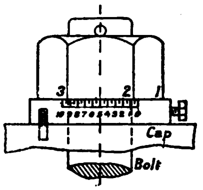

Fig. 10.—Method of Marking off Nuts.

Marking off Nuts.—For convenience in adjusting the bearings, and in order to provide a record of the adjustments made, the following plan will be found useful:—

Stamp a number on the nuts at each corner of the hexagon, near the face bearing on the washer.

The washer is prevented from turning with the nut by means of stops; mark part of the circumference of the washer off, in ten divisions of ½ inch in length, with a sharp flat chisel, around that part in view, number these divisions and subdivide them. The position of the nut can then be recorded by means of the marked corner most prominently in view, which coincides with a certain division on the washer—*e.g.*, in Fig. 10 write 2 on ½, or 3 on 9¼.

Leads.—In order to ascertain if a particular bearing requires readjusting, and to determine the amount of clearance, "leads" are taken. The method is to remove the top brass of the bearing, and to lay a length of lead wire $\frac{1}{16}$ inch in diameter ($\frac{1}{32}$-inch wire is often preferable, if procurable) half-way around the circumference of the journal towards each end. The top brass is then replaced and screwed down hard on the liners, so that the lead wires are squeezed to a thickness which indicates the amount of clearance at each end of the bearing. The amount of clearance should be the same at each end at the crown, and should increase gradually around the brasses towards the horns. These leads should be wound around a card on which the date and marks at which they were taken are noted, and the card can conveniently be stowed in a special box fitted up with separate compartments for each bearing. These leads, when subsequently compared with others taken at the same marks, will give an indication of the nature and amount of the wear in the interval.

To Refit a Bearing.—Open out, remove the top and bottom brasses, clean all working surfaces, clear the oilways, calliper the journal carefully, and ascertain if it is oval or tapered, refit the journal as required, and according to the means at disposal. Should the journal be found rough or scored it will probably be necessary to file it all over. In doing this, care must be taken to file it evenly, so as to form a new cylindrical surface perfectly co-axial with the original. After filing, it is customary (if the position of the journal admits) to "lap" the journal—that is, first to grip it with a pair of dummy half-bearings, preferably made of cast iron,* which are revolved on the journal to mark the hard places, which must be eased off. When this is completed, a pair of wooden copper-lined laps are smeared with very fine emery and oil; they are then screwed up loosely on the journal and are revolved until a smooth surface is obtained. Some engineers object to this last process, on account of the risk of small particles of emery being left; scrupulous care must, on this account, be taken to thoroughly clean all surfaces and all oil passages leading to them. The "lap" for a main bearing journal should be made of cast iron to cover about two-fifths of the circumference. If the journals are not lapped the filed surfaces of the journal must be carefully smoothed up by an oilstone.

The brasses are scraped or filed until a good bearing is obtained along the crown. All flaky metal must be removed. The brasses are eased away at the sides, since a bearing at this part serves no good purpose and increases the friction. To obtain a satisfactory bearing on the brasses of the connecting-rod they should be tried in place, secured by the cap, but if there is not sufficient time to repeat the process of putting up and taking down the bearing, then it is customary to try each brass on the journal, revolving it by hand; the journal having previously been lightly smeared with a very little red lead. The less marking used the more reliable is the surface obtained. This latter method is not trustworthy, because, although each half-brass may bear properly, yet, when connected in place, the line of bearing may be cornerwise, and not along the crown.

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* The "lap" should be strongly made and very accurately bored.

If brasses are lined with white metal, as is the practice in crank-pin bearings, and the white metal is much worn, the brass must be relined; for this purpose a mandril of the same size as the journal is necessary. This process is described later. Many engineers like the white metal to be "proud" of the brass, and, as the former wears, the latter may be cut down below the bearing surface. If this is often repeated the white metal would be too "proud" when renewed, but the brass-retaining edge can be brought up again, with some loss of bearing surface, by boring a groove at each end around the brass, and fitting raised circumferential brass edge-strips recessed in the grooves. This must, of course, be done before the brass is refilled.

To Adjust a Bearing.—Replace the brasses, but do not put the liners in place at the butt, replace the cap of the bearing, and screw it down tight, giving the spanner two or three light blows with a large hammer, in order to make sure that the bolt is well home. Observe the position of the nut on the washer, and record it, slack back the nuts the required number of the divisions marked around the circumference of the washer, as found by experience to give about the necessary clearance; observe the new marks, and then take leads at the proposed marks. Remove the leads for examination, and, if the clearance is not quite as desired, make the necessary alterations in the position of the nuts when the cap is replaced; then fit the liners to the new width required, slack back to insert them, and let them be firmly held by the cap when the nuts are tapped up to the new marks. Before putting a bearing together, always carefully oil the journal and brasses. When the bearing is re-adjusted, insert a crowbar between the brass and the crank arm, or connecting-rod fork, and move the bearing along the pin, through the length of the longitudinal clearance. This proceeding gives a satisfactory assurance that the bearing is not too tightly screwed up. The connecting-rod bearings of a large engine should be easily moved by one man, using a crowbar about 3 feet long. The crank should be moved into several positions during this test, so that it can be ascertained if the bearing is tighter in one position than another.

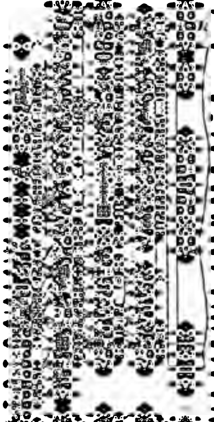
Record of Adjustments.—A record should be kept of all adjustments made in a special book with pages ruled out as follows:—

[illegible]

[illegible] HEAD.

[illegible]	Starboard Nut.		
[illegible]	Hard up	Left at	Remarks.
[illegible]	on 4¼	3 on 1¾	Re-adjusted; went up 1 div.
[illegible]	on 4¾	3 on 2¼	Went up 2 div.; refitted.
[illegible]	on 4¾	3 on 2¼	Tried.
[illegible]	on 5	3 on 2⅛	Re-adjusted.

[illegible] ertical Engine.— [illegible] thout difficulty into
[illegible] ing-rod. To remove
[illegible] e engine up on the
[illegible] e piston and rod by
[illegible] ecial bolts, through
[illegible] tted to secure the
[illegible] hese bolts over the
[illegible] Special plates are
[illegible] he guide face under
[illegible] same purpose. Fit
[illegible] own in the sketch
[illegible] nd from the fixed
[illegible] pper brass to the
[illegible] engine down, taking
[illegible] g-rod always slopes
[illegible] resses against the
[illegible] osshead pin is thus
[illegible] he top brass, which
[illegible]



[illegible] liable to wear oval,
[illegible] urfaces only being
[illegible] f the pins are made
[illegible] te metal. The pins
[illegible] ssrs. Humphry and
[illegible] 90° around a longi-
[illegible] aces will form the

working faces. To effect this change it will sometimes be necessary to cut new grooves across the pin to allow the crosshead bolts to be placed in position. If the pins are shrunk in place they cannot be readily moved; the pins must then be filed on the large diameter. Some makers flatten the sides of the pins to assist the process of refitting. Particular care is necessary in adjusting the brasses of a connecting-rod which has a bearing on each side of the crosshead (see p. 114).

To Open Out the Crankhead.—The crosshead bearing must be connected up and the piston and rod hung up as described in the previous paragraph. To lower the bottom cap of the crank-head it will be found convenient to keep two pairs of pulley blocks, small enough to allow the lower pulley blocks to descend through the holes for the crank-pin bolts in the connecting-rod end. If the upper blocks be hung from eyebolts screwed into the crosshead-bolt ends a straight lead will be secured. To get at the upper crank-pin brass, the piston being hung as described above, the connecting-rod must be hung by means of a rope tie from a point in front of the engines, and the crank shaft must be revolved ahead until the crank pin is free from the upper brass.

All large bolts should have tapped holes in their ends for eye bolts, and these holes should be kept plugged with short bolts when the engines are at work.

Generally speaking, it requires a working day of eight to ten hours to examine, clean, and replace either of the connecting-rod bearings of an engine of 4500 I.H.P.

The Main Shaft Bearings.—These do not require adjustment at such frequent intervals as those of the connecting-rod. It is a comparatively simple matter to lift the cap and top brass; if the shaft be then turned through half a revolution, the condition of the journal can be ascertained. Should one of the main bearings have been heated, the lower brass should also be examined. The removal of the lower brass requires more care than manual labour. A clamp, B (Fig. 12), is secured on the crank-arm, A, by the bolt, C. If the shaft be now revolved by the turning engine, the nut, D, screwed on to a small projecting stud on the clamp, will butt on the edge of the bearing, and as the shaft continues to revolve, the bottom brass will be turned out of its seating. The centrifugal lubricator must generally be removed before the clamp is fitted, and also any stops fitted in the flange of the

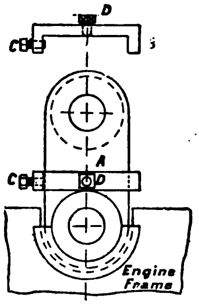


Fig. 12.—Clip for Removing Lower Brass of Main Bearing.

bottom brass to prevent it revolving. The brass is replaced by the use of the same clamp; its weight will generally be sufficient to ensure its turning back smoothly, but, as a safeguard, a suitable guide can be made of a light plate bent to the same shape as the back of the brass; this plate is placed over the brass when the latter is laid on the top of the shaft, and is secured by means of deep washers and nuts on the bolts of the main bearing. It is not necessary to fit special supports for the crank shaft whilst a bottom brass is withdrawn.

Clearance in Bearings.—The number of divisions the nuts of each bearing should be slacked back for proper adjustment should be known and recorded in every ship. It unfortunately happens that undue strains or small errors of workmanship may affect the truth of a particular journal and necessitate more than a normal amount of clearance. Speaking generally, main bearings are not so tightly adjusted as those of the crankhead; the former are liable to get out of line, due to an alteration of form of the hull; moreover, the direction of application of the load is more constant, and consequently the circulation of oil in the bearing is less free. The method of checking adjustments by taking leads has been already described, and the following rules give what may be considered as good "close" adjustments for true journals of 4 inches in diameter and upwards; below 4 inches in diameter a small addition should be made:—

Crankheads.—Thickness of lead to be $\frac{1}{1000}$ of an inch for each inch of diameter of journal.

Crossheads.—Thickness of lead to be $\frac{1\cdot25}{1000}$ of an inch for each inch of diameter of journal.

Main Bearings.—Thickness of lead to be $\frac{1\cdot6}{1000}$ of an inch for each inch of diameter of journal.

It should be observed that many bearings will probably come under notice, in which the necessary clearance considerably exceeds the above normal allowances.

Solid C.I. pistons or piston valves working in C.I. cylinders should be made an easy fit. This adjustment corresponds with a looseness of $\frac{1}{1000}$ to $\frac{3}{1000}$ of an inch for diameters of piston varying from 3 to 18 inches. Solid G.M. or phosphor bronze pistons or piston valves working in C.I. cylinders must be finished with a clearance sufficient to allow for the difference of expansion of G.M. or cast iron; but, since the cylinder may be a somewhat complicated casting and not free to expand in every direction, the clearances should then be calculated from the linear coefficient of expansion of G.M., on the assumption that the expansion of the cast-iron cylinder is negligible. Thus (allowing a rise of temperature of 350° F., 300° F., and 250° F. in the H.P., I.P., and L.P. cylinders respectively), the clearances should be—H.P., $\frac{44}{1000}$ inch; I.P., $\frac{38}{1000}$ inch; L.P., $\frac{32}{1000}$ inch on each 12 inches of diameter. This adjustment provides for an extreme case; but, if the cylinder is a simple casting and free to expand, these clearances can be reduced one-half with safety.

Piston spring rings for large cylinders are usually cut across their width to allow them to be compressed into place and so exert a light pressure against the cylinder barrel; moreover, they are required to open out further as the rubbing circumference becomes worn. Such rings are turned up of an external diameter $\frac{1}{8}$ of an inch per foot of diameter larger than the bore of the cylinder; the length of the portion cut out is arranged so that the ring shall have a certain amount of opening at the cut ends when first inserted in the cylinder. "Restricted" rings are turned up with an excess external diameter of $\frac{3}{32}$ of an inch per foot of diameter.

The opening left in cut C.I. spring rings when placed in position in C.I. cylinders should be about $\frac{50}{1000}$ inch per 12 inches diameter, measured across the cut and around a circumference. Gunmetal spring rings in C.I. cylinders should be allowed $\frac{100}{1000}$ inch opening per 12 inches of diameter to allow for the difference of expansion of the metals. This rule agrees with well-tried practice and also with the coefficients of expansion, allowing for a rise of temperature of 350° F. Thus—

Linear coefficient of expansion of G.M. = ·0000104 for 1° F.
" " C.I. = ·0000065 "

∴ Difference of increase of circumference of G.M. and C.I. for 12 inches diameter and 350° F. rise of temperature is—

$$\cdot000004 \times 350 \times \pi \times 12 \text{ inches} = \frac{53}{1000} \text{ inch.}$$

(To be added to the allowance for C.I. spring rings.)

The amount of opening of the spring ring might be reduced in the I.P. and L.P. pistons; but, since these openings are generally made steam-tight by the tongue piece, it is not considered necessary to make any difference.

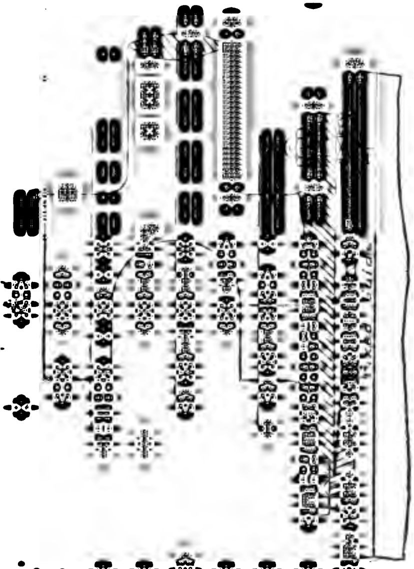
It may be necessary to provide some means of packing out a cut spring ring which is not "restricted" as regards the amount of wear permitted. If the wear of a free spring ring should be rapid and abnormal, it may well happen that the piston will acquire sufficient drift in the cylinder to allow the edge of the junk ring to catch on the top edge of the cylinder liner with disastrous results to some part of the machinery. The designed radial pressure of the spring ring on the cylinder barrel should not produce any excessive wear, but this radial pressure may be augmented by steam pressure against the inside circumference of the ring; and, when working at full power, the rate of wear may thus become abnormal. On such occasions, if experience suggests the desirability of a precaution, the spring ring may be made solid by filling in the slotted holes for the tongue-piece bolts, and so limiting the wear of the ring at the expense of its steam tightness.

The ordinary backing of a large spring ring does not always provide for the insertion of additional liners as the ring becomes worn, though it should be noted that they may be necessary to ensure proper control of the piston.

The clearance of a cast-iron spring ring between the junk ring and piston flange should be about $\frac{1}{1000}$ to $\frac{2}{1000}$ inch for widths of spring ring of from 1 to 6 inches. The clearance of a gunmetal spring ring similarly fitted in a H.P. steel piston must be greater than in the foregoing case by $\frac{1.5}{1000}$ inch for each inch of width, otherwise it may be nipped when heated; a corresponding allowance should be made in I.P. and L.P. cylinders. To find the clearance of a spring ring between the piston flange and junk ring, two lengths of $\frac{1}{16}$-inch lead wire should be used, one length laid around the circumference on the top surface of the ring and one between the junk ring and its face on the piston. If the two lengths of lead wire be then squeezed by screwing down the junk ring, the difference of thickness of the leads gives the clearance.

The Crosshead Guide.—The liners for the crosshead slipper require frequent adjustment. To lower the slipper screw eye bolts into the top edge and support the slipper by thin steel wire rope secured to the eye bolts and led over a stout round bar fixed across the top of the guide. Let the steel wire run over this round bar, used as a pulley, and attach a block and tackle to the end of the wire in front of the engine. Remove the bolts securing the slipper to the crosshead. Insert a screw-jack between the piston-rod and the fixed guide, and force the crosshead away from the ahead guide until the astern surfaces bear. The slipper can now easily be lowered and the thin steel wire will run behind the crosshead, through the space left by the slipper as it descends; whereas a thicker sling of hemp rope would jam. Clean the surfaces and remove all flaky metal, deepen the oilways as required. Slippers will sometimes be found worn thin in the middle of their length, as shown in an [illegible] that the slipper is [illegible] which has a higher [illegible] d; for this reason [illegible] bolts as shown at [illegible] the bolt at A clips [illegible] ard in the middle, [illegible]

[illegible] the centre along [illegible] ing of the foot of



[illegible] Work.

[illegible] gh to provide the [illegible] which the wear was [illegible] les. It is difficult [illegible] st planed parallel. [illegible] es should be tried [illegible] slipper should be [illegible] iddle of its width. [illegible] B, in order that [illegible] slipper and crosshead. If an additional liner has been placed in position, the slipper should go up without any sticking or coaxing when the crosshead is forced into contact with the opposite guide surface, and at the same time there should be no "shake" in it before it is secured in place. The amount of clearance required is from $\frac{6}{1000}$ to $\frac{10}{1000}$ of an inch, when cold. Experience of the particular fitting is required to determine the thickness of the additional liner required and it is better to fit the thinner of two possible liners in preference to one which may prove too thick, because this adjustment is one of the most difficult on the engine, and therefore needs most caution.

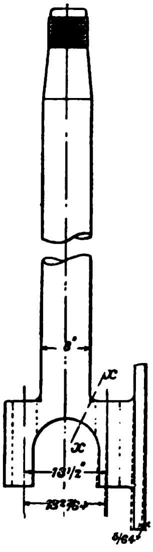


Fig. 14.

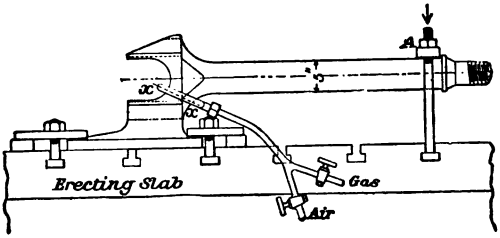


Fig. 15.

Fig. 14 illustrates a defect which developed in a large piston-rod, but which more often occurs in light piston-rods of fast-running auxiliary engines, and also in those of some torpedo boat destroyers. In consequence of an abnormal strain, the jaw of the crosshead was closed in, so that the centre line of the bolt, and also the guide surface, were found to be no longer parallel to the rod. This defect gives a swaying motion to the rod, and produces a leaky gland. To discriminate between this defect and a bent rod, it is necessary to put the piston-rod in a lathe, when the cylindrical portion may be found to run true, and the alternative defect may be demonstrated by bolting the surface of the crosshead shoe down on a surface plate and then trying a scribing block along the rod. It has been found possible to open out the jaws of piston-rods up to about 4 inches in diameter by bolting the guide surface down firmly on a strong erecting plate, as shown in Fig. 15, and, after heating the jaw locally at the line $x x$ to a very dull red by means of gas jets from a Bunsen burner of suitable shape, the rod can be drawn down parallel to the guide surface by means of bolts rove through a strongback placed as shown at A. If the heat is judiciously controlled and the rod is allowed to cool slowly, the cylindrical part will be found still true when subsequently tested in a lathe.

To test the truth of the guide surface, two sets of measurements are necessary:—1st, To find if the surface is parallel to the centre line of the cylinder:—A steel piano wire of about forty-thousandths of an inch in diameter is stretched as indicated in Fig. 16. It is attached to two balks of timber secured respectively across the top of the cylinder and across the gap of the crank, as shown. The wire is stretched taut by means of an eye bolt at the top end, and each end can be moved in either direction by means of set screws pressing against a sliding block mounted on a base plate fixed on each piece of timber, as shown in greater detail in Fig. 17 in elevation and plan. To adjust the wire to the centre line of the cylinder, measurements of the radii are accurately taken by means of trammels at the positions *cc* and *dd* at each end of the cylinder, measuring to an unworn turned circumference. The greater the distance between *c* and *d*, the more accurate will be the position of the centre line. Measurements are then taken from the top, centre, and bottom of the guide surface to the stretched wire, using a trammel of a form as shown

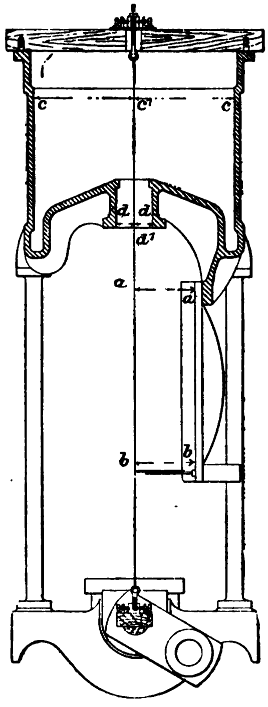


Fig. 16.

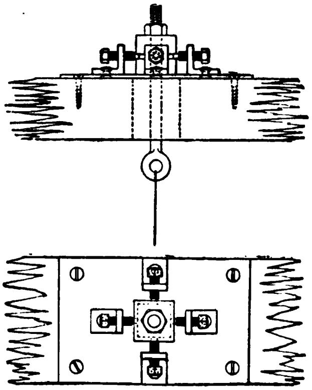


Fig. 17.

in Fig. 18, which will be found more convenient and accurate than callipers for this purpose.

2nd, To measure whether the guide surface is parallel to the centre line of the shaft. First test the truth of the crank-pin, if any doubt exists, and prove that it is in line with the shaft journals and of uniform diameter. A stiff steel straightedge, with a scriber suitably attached, is then placed diagonally across the face of the guide surface, and the distance between the face of the straightedge and the surface of one end of the crank-pin is measured. The straightedge is then sloped in the opposite direction and a similar measurement is taken at the other end of the pin. The guide surface should then be packed so that these two measurements are identical, and the thickness of packing required on one side or the other should be noted. From the two sets of measurements detailed above, the guide faces can be set up on the planing machine in the position required to produce a true surface, due allowance being made for the expansion of the cylinder when hot.

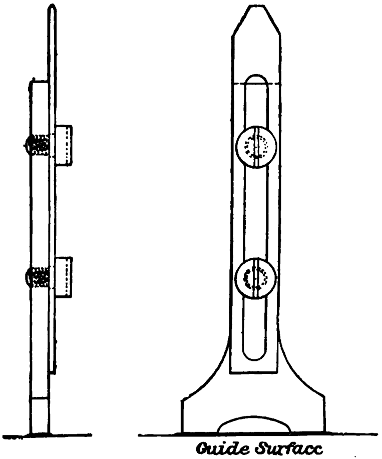


Fig. 18.

The effect of the expansion of the cylinder on the truth of the guide surface varies with the kind of columns employed. If the cylinder is carried on four cylindrical forged columns of about the same diameter, it may be assumed that the front and back columns will open out equally at the top when the cylinder is heated, while the feet of the columns will open to a much less extent. Intermediate points on the guide surface will therefore open by an amount proportional roughly to the distance from the feet of the back columns. To allow for this expansion, the guide surface should be adjusted when cold to lean in to the centre line of the cylinder at the top end. In torpedo boat destroyers an allowance of $\frac{10}{1000}$ inch at the top end of the guide surface has given good results.

In large engines, when the back columns carrying the guide surfaces are formed of heavy stiff castings and the front columns are cylindrical forgings, the effect of the expansion of the cylinder is generally to increase the distance of the guide surfaces from the centre line of the cylinder and the clearance of the rod in the gland should be greater on the side nearest the guide surface when cold. In this type of engine the clearance of the slipper between the ahead and astern guide surfaces should be $\frac{6}{1000}$ to $\frac{10}{1000}$ of an inch.

In another type of engine fitted in modern battleships, the front and back columns are of similar design, and are formed of stiff castings. Measurements taken in one ship showed that the space between the ahead and astern guide surfaces increased by $\frac{21}{1000}$ of an inch at top and by $\frac{17}{1000}$ of an inch at the bottom in the H.P. engine when hot; and in the L.P. engine the distance between the guide surfaces increased by $\frac{7}{1000}$ of an inch at top and bottom alike. In a second ship with similar columns, the space between the ahead and astern guide surfaces increased by $\frac{20}{1000}$ to $\frac{25}{1000}$ of an inch at top, and by $\frac{6}{1000}$ to $\frac{10}{1000}$ at the bottom, in H.P., I.P., and L.P. engines alike; in this case there was some discrepancy in the amount of openings of the forward and after guide columns of the same engine. This diversity in similar ships points to the necessity of making measurements and allowances in the setting of the guide surfaces suitable to each particular case. In this type of engine the crosshead slipper should just touch both the ahead and astern surfaces at the top end when cold.

The Line of Stroke.—The centre line of the piston-rod should coincide with the central axis of the cylinder, but it may be displaced from either of the causes, (*a*), (*b*), (*c*), or (*d*), mentioned below. The most common indication of such a displacement is that the rod works through the gland with a swaying motion, so that the clearance at a point on the circumference varies through the stroke. This swaying motion is usually accompanied by trouble with the gland packing, which must be left loose and possibly leaky. Frequently, also, the side clearance of the slipper is affected, and one side, or opposite corners, may rub hard.

If the rod sways in an athwartship direction, so that the clearance at the back and front of the gland varies, the cause may be due to abnormal wear of the piston spring rings and carriers, or to either (*a*) or (*b*).

(*a*) The piston-rod may be bent (see p. 118); this defect is indicated if the clearance between the piston and cylinder cover is not uniform all around the circumference, or if the measurements differ from the previous set taken, showing that the piston is tilted. A very good method of testing the straightness of the piston-rod is to centre the piston in the cylinder and then measure down from some turned surface, such as the cylinder flange, to the top turned surface of the junk ring at points selected around the circumference; these measurements should be equal. As a piston-rod often bends close up to the collar, this method is to be recommended in addition to the use of a straightedge applied to the length of the rod.

(*b*) The slipper may require lining up, indicated by an abnormal clearance between the ahead or astern guide surface and the corresponding rubbing surface of the slipper, accompanied by a heavy knock towards either or each end of the stroke. Or, again, if the surface of the slipper is not evenly balanced above and below the crosshead pins, unequal wear may occur, the piston-rod will be deflected, and the piston will bear harder on either the front or back of the cylinder until the worn surface is lined up.

(*c*) If the piston-rod sways in a fore and aft direction, the cause may be (*d*), or that the bearing surface of the crank pin or gudgeon pin may not be perpendicular to the axis of the cylinder, or the brasses of either of these bearings may be improperly adjusted so that the connecting-rod is "thrown." In those engines provided with a gudgeon pin on either side of the crosshead, the crosshead brasses require frequent and careful adjustment to ensure that the two lower brasses are of the same thickness, because the wear is generally unequal. The characteristic indication of these defects is that the side clearance of the crank or crosshead brasses is incorrect, and the brasses show signs of heating unless loosely adjusted, when they will probably work with a knock.

The method of ascertaining if the crank pin is parallel to the axis of the crank shaft is given later. Assuming the crank pin and crosshead pins are true, the method of swinging the connecting-rod is used to correct the crank and crosshead brasses. First disconnect the crosshead end of the connecting-rod, and take the weight of the piston and rod at the top of the stroke on the portable strongback provided. Remove the top manhole or cover of the cylinder and set the piston true in the cylinder, measuring between the barrel and an unworn circumference of the junk ring. Remove the gland packing and set the piston-rod true in the stuffing-box. Remove the liners from the crank-pin brasses, turn the engines until the lower crosshead brasses are just clear of the gudgeon pin. Set the connecting-rod with the known proper amount of side clearances between the ends of the crank-pin brasses and the crank arms. These side clearances were probably originally equal, but, owing to the wear of the thrust collars, the crank shaft gradually moves forward, and the amount of such wear at any time should be accurately ascertainable by comparison with marks or measurements made when the engines were new. If there is no such record available, the correct position for the crank-pin brasses may be ascertained by stretching a wire through the centre of the cylinder, as described on p. 111. This process, however, requires more time than is available during a short stay in harbour, and, in that case, the approximate position of the crank-pin brasses must be estimated from observations of the amount of clearance in the thrust rings and a comparison of the position of the brasses of the other crank pins on the same engine. The crank-pin brasses, having been spaced, are drawn up to a close fit on the crank pin, and the engines may be turned up if necessary, so that it can be seen whether the forks of the connecting-rods are symmetrically situated, with equal side clearances on the two crosshead journals. If these side clearances are not equal, the thick ends of the crank-pin brasses must be filed and scraped until the connecting-rod is thrown true. The necessary thicknesses of the lower brass (or brasses) of the fork end can then be ascertained by careful measurements made between the surface of the pin and the machined bed for the brass in the fork end of the rod. These brasses should then be fitted and adjusted with equal "leads." After fitting, the accuracy of the crosshead brasses can be tested by swinging the connecting-rod from the top end and noting that all side clearances are correct.

(*d*) If the thrust collars are worn so much that the original clearance between the after end of the crank-pin brasses and the crank arms has entirely disappeared, then the bottom end of the connecting-rod would be forced forward. To remedy this defect, the thrust collars should be re-metalled, or the thrust block should be put bodily aft by the required amount. The latter adjustment will probably necessitate some refitting of the eccentric straps and the eccentric-rod pins.

To test if the axis of the crank pin is parallel to that of the crank shaft:—First verify that the crank pin is of uniform diameter; the crank shaft can then be placed in a lathe and set true to the journals of the main bearings. The surface of the crank pin can then be tested in four positions of the crank by means of a scribing block rested on the lathe bed. If the shaft is a large one it may not be convenient to remove it from its bearings; in that case a long and very stiff steel straightedge is required. The crank is placed on the top centre, and the straightedge is clipped to the shaft in a position above the crank pin and is set parallel to the axis of the journals in the main bearings. It is first necessary to remove the caps of the main bearings and to calliper the journals to verify their diameters. The straightedge being parallel to the axis of the shaft, measurements are made between the crank pin and straightedge all along the length of the former. The crank is then turned to the bottom centre, and the straightedge is set as before and the measurements repeated. Next place the crank horizontal and lay a large surface plate across the arms and set parallel to the axis of the journals, measurements can then be taken between the plate and the crank-pin surface; turn the crank through 180°, and set the surface plate and measure as before. These four sets of measurements will give all the information required to verify, or correct, the axis of the crank pin.

To test the Setting of the Axis of the Crank Shaft.—The wire stretched through the centre line of the cylinder can be used to verify the setting of the axis of the crank shaft, but for this purpose the lower end of the wire must be secured to the crank-pit plates. The crank is then placed as near its top position as is possible, and the distance between the wire and the inside surface of the crank arm is measured off on a special trammel. The crank arm is then turned round as near to the bottom centre as is possible, when the distance between the wire and the inside surface of the crank arm should be the same as in the top position, if the axis of the shaft is perpendicular to the line of stroke. Care must be taken that the crank shaft does not shift forward or aft when revolved, to which end it may be forced up to the thrust collars before each measurement is taken.

Link Gear.—The slide-block brasses require frequent attention. The brass under the link should first be refitted, and then the weight of the valve should be taken by a suitable support in such a manner that the bottom brass touches the link bar whilst the top segment brass is free; the latter can then be lined up. Before lining up the block brasses it may be necessary to refit the link; it will generally happen that most of the wear on the link bar occurs towards the middle of its length on the ahead half; the reason being that engines are generally run more or less linked up. If the wear on the ahead side of the link is considerable, it will be necessary to file the bars on the astern side till a uniform depth of bar has been obtained. Care must be taken to preserve the proper curvature, and a stiff template may be necessary for this purpose; if a template is not available, the link-block must be frequently tried on the bars. If the link is not refitted, the segment brasses must be adjusted at the unworn part of the bars near the astern eccentric-pin, otherwise a hot link-block may result when the engines are run in full gear, The surface of the link bars must be kept very smooth by the frequent application of an oilstone, in particular it should be applied if the bars have been refitted. After adjusting the slide-block brasses, try the links with the hand reversing gear to make sure that they run freely. When it is necessary to examine the surfaces of the eccentrics, be careful to support the weight of the slide valve before loosening the eccentric-rods. Ascertain that the butts of the two parts of which the sheave is composed are fair, as the steel part is liable to spring out when tight on the shaft; this spring would cause a slight cutting edge to appear at the butt, and would result in abrasion and a warm eccentric-strap. The sheaves must be callipered to detect if they have worn oval, in which event they must be rounded up. Examine the sheaves carefully to see that all fastenings and keeps are secure and that the webs of the sheave are sound; sheaves have been found with cracks extending from the corner of the key-way. See that the feather securing the sheave to the shaft is tight. If the straps are brass-lined, the screws securing the linings should be tapped with a hammer and examined to see that they are secure; if any are loose, or suspected to be, they should be refitted. The straps should have their bearing surfaces well cleared away at the horns, and should be clear of the sheaves at the fillets. The straps should be adjusted loosely enough to allow the eccentric-rods to be free to swing down by their own weight if released from the link. It is important that the oil-ways should be led to carry the oil uniformly over the surface of the strap, and they should be rounded so that no cutting edge is formed.

Weigh Shaft.—The bearings of the weigh shaft do not require frequent adjustment, the shaft itself being stationary when the engines are working. It will be necessary to remove the weigh shaft from time to time to clean the bearings and journals, which have a tendency to rust; this should be done whenever the oil running through the bearings brings rust in suspension; it is not necessary to disconnect the drag links. Sling the weigh shaft from above and remove the caps of the bearings; the whole of the weigh shaft can then be moved out of the bearings by the hand reversing gear, and can be replaced, with a little care, by the same means.

Cylinders and Pistons.—Cylinders should be opened out constantly, and particularly on all occasions when a ship arrives in harbour for a stay of some days; the internal surfaces should be thoroughly dried and cleaned with cotton waste and turpentine; the working surface should show a uniform polish all round. After cleaning, spread oil over the surfaces with the palm of the hand. To examine the piston lift the guard ring and junk ring and withdraw the spring ring. The spring ring, if it is wearing properly, should be of a uniform thickness round its circumference, and it should have spring enough to support its own weight when placed at any position throughout the length of the cylinder. If it cannot be pushed down by hand, it is too tight. See that the opening at the transverse cut is sufficiently wide. If the piston-rod is slightly bent, or the cylinder is not in line with the stroke, the cross section of the spring ring will wear wedge-shaped. Before closing up a piston after an examination, try all the springs with a tommy to see that the pressure around the spring ring is uniform. The spring supporting the tongue piece is more liable to deterioration than the others, and should be specially examined. See that all the split pins are replaced above the nuts on the studs securing the guard ring for the junk-ring nuts. Before closing up the cylinder the engineer should carefully examine the steam ports and see that no tools have been left by the workmen. The steam passages are often used as shelves or stowholes during a repair; they should be plugged up or covered whilst the work is in progress. A large piston can be examined and closed up in a day if the cylinder cover is not removed.

Piston Clearance.—To test the piston clearances at each end of the stroke, take off the top and bottom manholes, make a number of plugs of red lead mixed with plumbago, and place from eight to twelve at uniform intervals at a certain radius (as large as possible) around the cylinder bottom, and also a like number on top of the piston, then turn the engines through a revolution. The plugs can then be collected, arranged on a plate as they were placed in the cylinder, and can be measured. The plumbago will prevent them sticking to either surface. This method is very useful as a test for a bent piston-rod, because if the piston-rod is bent the piston will slope and the clearances will not conform with former records. The most accurate straightedge applied to the rod does not afford so good a test as that obtained by the above method. It is essential that the plugs should be placed in the same positions on each occasion of testing. The results will be more valuable if the clearances are obtained on the first test, both by the "bumping" method and also from the plugs; when, if any differences caused by a protuberance on any of the surfaces exist, the corrections can be noted and applied on future occasions. The plug method, with the foregoing precautions, will then avoid the necessity for disconnecting the crosshead bearing on future occasions.

Adjustment of Pistons of Horizontal Engines.—The pistons of horizontal engines require lining up to the central position from time to time, owing to the wear of the spring rings on which the weight is supported. The process is as follows:—Remove the packing from the piston-rod stuffing-box. Remove the plug door from the back end cylinder cover to give access to the piston; if the cylinder is not large enough to allow two men to work inside, it will be necessary to take off the cylinder cover. Turn the engines until the piston is at the front end of the stroke, remove the guard-ring and junk-ring bolts, which should all be marked to show clearly to which hole they belong. The junk ring can now be moved to the back end of the cylinder and there be fixed out of the way, so that there is no fear that it will fall. The turned edge of the body of the piston is now exposed to view, and as this edge is central with the turned outer flanges of the piston it may be taken as a guide to ascertain the wear of the piston. This is done by measuring the distances A and A^1 from the turned body of the piston to the top, and to the bottom of the cylinder respectively, along the vertical diameter; and also the distances B and B^1 from the turned body of the piston to the cylinder along the horizontal diameter. Then $\frac{1}{2}(A-A^1)$ is the amount the piston is down from the central position, and $\frac{1}{2}(B-B^1)$ is the amount the piston is out from the central position sideways. These measurements should be checked by measuring the position of the piston-rod in the stuffing-box.

Having obtained the position of the piston the next thing to do is to remove the piston springs, which can generally be done by exerting a strong grip on a pair of pliers, and while doing so the fit of the spring ring at the top of the cylinder can be observed. Now measure the thickness of the spring ring at intervals round its circumference and see whether it would not be advantageous to turn the ring so as to bring another portion of its circumference to the bottom; but remember that, if this is done, it will be necessary to renew the measurements before deciding on the thickness of the liners to be fitted.

The weight of the piston at the bottom is usually taken by a solid piece of iron fitting tightly between the body of the piston and the spring ring, and extending for about one-third of the circumference. This piece is called the "cod" piece, and if it is necessary to line up the piston this must be done by inserting liners between the cod piece and the body of the piston. Presuming that liners have to be fitted, the next operation is to lift the piston, which is best performed by means of a hydraulic jack butting under the piston-rod nut. Care must be taken, by the use of a baulk of wood, that the foot of the jack does not injure the cylinder wall, and that the lift is no more than is necessary —*i.e.*, say, $\frac{1}{32}$ in. above the central position. Now remove the cod piece or pieces (it is sometimes made in two or three lengths), and from it mark off the shape of the liners required, which may be made of any suitable material. Sheet iron is preferable, but, as there is not such variation in the thicknesses in which iron is rolled as in some other metals, it is often more feasible to make the liners of copper or "sheet tin." Before fitting them in place it is as well to think of the nature of the wear of the piston-ring. It is $\frac{1}{2}(A\text{-}A^1)$ in the centre, but this wear gradually decreases toward the sides, being probably reduced to nil at points on the horizontal diameter. Therefore, the liners will require thinning at their ends; otherwise the piston will bear on them before it does on the liner in the centre. This being done, the liners are now ready for fitting; put them in place, making sure that they cannot work away from the cod piece to which they are fitted. As slots in the cod pieces are made to fit over small stops in the body of the piston the security may be assumed, but it is well to examine and see that the precaution has been taken. Now lower the piston down on the liners and cod pieces, and again measure to ascertain if it is central; then, presuming this to be satisfactory, proceed to replace the springs. These should be pushed into place with a moderate pressure and, while doing so, the spring ring—which will probably have sagged away from the cylinder wall under its own weight—will be gradually pushed back into its proper position. The springs must be so set as to be able to push the spring ring up into contact with the cylinder wall when the piston has worn down about $\frac{1}{8}$ in. Now examine the piston spring ring and springs to see that all is as it should be, and then replace the junk ring, screwing up the junk-ring bolts, each in its proper place. The next operation is to replace the guard ring or set screws for junk-ring bolts, whichever plan is fitted; and here some slight adjustment may be necessary as the bolts may be screwed up a little tighter than before. This can be remedied by fitting thin tin or other washers under the heads of the bolts. Now fit the split pins to secure the guard ring, or set screws. After another examination of the piston to see that all is correct, the cylinder will be ready for cleaning, oiling out, examination, and closing up.

Useful points in the adjustment of a piston are the provision of a couple of bags or mats to afford foothold for working in the cylinder. Next, the provision of a suitable spanner for the junk-ring bolts. With small pistons of V-section a box spanner, with a shaft sufficiently long for the wrench used with it to clear the piston-rod nut, is necessary. Junk-ring bolts are usually fairly tight, and a good long wrench or Samson is advisable. Lastly, in order to get a fair lift under the piston-rod nut, a piece of wood should be cut flat on the under side for the head of the jack, and with an angle cut out at the top to take the piston-rod nut. Do not forget to repack the piston-rod gland.

When the wear of the spring ring has been excessive, pieces of metal may have been blazed into the walls of the cylinder. If the walls are rough they can be improved by smoothing them up with an oilstone. It may be here remarked that, when wet steam is used for the purpose of lubricating the cylinders, it is absolutely necessary to take off all manhole doors, and dry up and oil down the cylinder walls after getting into harbour. Similarly, oil should be introduced to the slide-valve faces and should be well distributed over them; otherwise the walls and faces will be spoilt by rust.

Cone on Piston-rod.—It is often a difficult matter to withdraw a piston-rod from its piston; to facilitate this operation for the next examination, coat the cone of the rod with a mixture of plumbago and mineral grease whenever the piston-rod is withdrawn from the cone.

Various special means are now provided with the object of enabling the rod and piston to be parted. A strongback is provided which rests on the end of the rod after the nut has been removed. Studs pass through the strongback and are temporarily screwed into the piston hub, and the joint of cone and rod is forced apart by means of nuts screwed on the studs above the strongback. The studs may be secured in a clamp, which is made in two halves bolted together around the hub under a rim, cast on the circumference of the hub and flush with the upper surface. There are various other similar devices, of which the "nut extractor," fitted in the destroyers, consists of a large nut, bearing on the end of the rod and screwed down on a fine pitched thread, cut on the hub of the piston.

Method adopted to remove a piston which was firmly seized on the rod.—A furnace, H, was fitted around the rod, and the latter heated by a charcoal fire until it had expanded $\frac{1}{4}$ in. in length, by which time it was red-hot for nearly 2 ft. of its length. The furnace was then knocked away and lowered into the crank pit, and the steel struts, F, F (Fig. 19), were swung into place between the crosshead and stuffing-box. Wedges were driven in at G, between the struts and small blocks, the latter being of a suitable shape and fitting into the crosshead bolt holes. Inside the cylinder an annular cast-iron ring, E, made in two halves bolted together, was accurately fitted between the piston and stuffing-box. As the rod cooled, the pressure was thus transmitted from the crosshead to the piston. When the struts were in place, a water jet was played on the

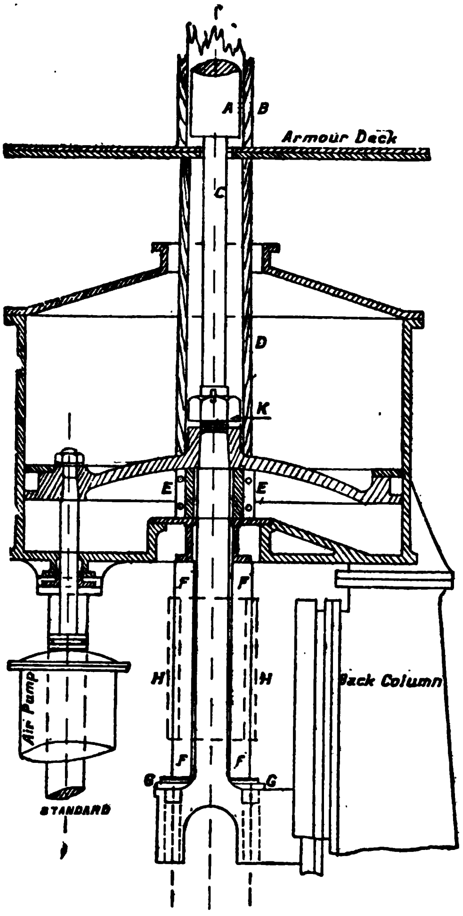


Fig. 19.—Method of Withdrawing Piston-rod.

heated rod to cool it, and, at the same time, a heavy monkey, A, was dropped on the drift, C, so that the blow was transmitted to the piston-rod, and caused vibration. At the third blow the piston and rod parted, and the nut, K, which had been slacked away, held the piston-rod from falling.

The cylinder was 96 ins. in diameter, the rod 8½ ins. The furnace was 2 ft. 6 ins. long, made in two halves hooked together; it had an annular space 2 ins. wide around the charcoal, through which the blast was applied to the charcoal fire, which was 3 ins. thick. The struts were 4½ ins. square in section. The cast-iron ring, E, was 2 ins. thick. B and D were wood casings forming guides for the monkey and drift. The monkey had a 6-foot drop and weighed about 5 cwts. Previous to this successful method the monkey had delivered very many blows, whilst the hub of the piston had been surrounded by a bath of 4 cwts. of molten lead, and a hydraulic press supported by struts from the armour deck had exerted a calculated pressure of 150 tons. The piston resisted every effort of the ship's staff for more than a week. At one time the piston was heated by gas jets issuing from a 1½-in. gas pipe coiled under the piston, and the monkey delivered its blows, which were transmitted by the above hydraulic press, the latter being of a special pattern designed for lifting the heavy barbette guns when under repair.

The first method described was successful in several other instances in which great difficulty had been experienced.

The rod, on removal, was straightened by hydraulic pressure, and, after being skimmed up, was again serviceable when its length had been tested and adjusted.

Method of Straightening Bent Piston-rods.—If the diameter of the rod is very small, and the bend is a comparatively long one in the middle of the length, the rod can be placed between the centres of a lathe; it is then tested by revolving it under a scribing block, and straightened by means of a powerful hand lever.

For a large rod, the rod should be slowly heated until the bent part is just red. A wood fire should be used, in order to prevent the rod scaling, and great care must be taken to prevent the rod being made too hot. The rod is then placed in a heavy lathe and forced into a straight line by means of a strongback clip. The strongback bears on the rod at three points, the outside two of which are underneath the rod and the middle one above and between them. The middle point of contact is made by an adjustable screw which applies the straightening force. The same principle is used in the design of the hydraulic jack (Fig. 20), which is used for large rods. It will be seen that no strain, beyond that caused by the weight of the rod, is transmitted to the lathe centres.

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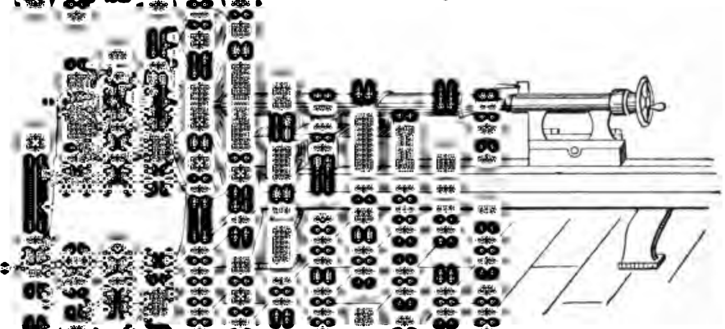

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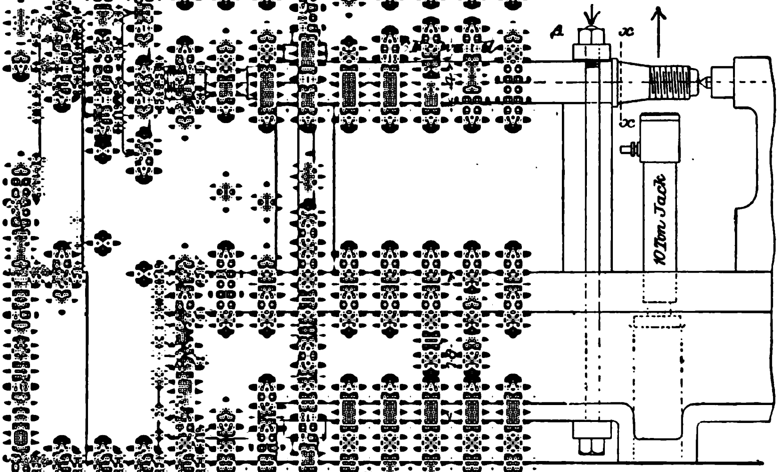


Fig. 21.

[illegible] that a lathe with [illegible] should be selected, [illegible] moment. Before the rod is fixed for the application of the pressure it must be revolved and marked to indicate the nature of the bend; the part where the bend occurs, say at *xx*, should then be heated locally by a Bunsen burner made of suitable gas piping bent to fit around the rod with jets of gas playing all around its circumference. The heat should be discontinued when the rod is just showing red.

The rod is then clamped down on the blocks in the proper position, as previously determined. When the hydraulic jack is applied the forces acting on the rod are as shown by the arrows; it is evident that the holding down bolts, A, should be as nearly in a line with the foundation bolts as possible. The hydraulic jack should be seated on the foundation block of the lathe. The rod surface should be protected by copper sheets at the points of application of the forces. Rods of larger diameter than about 4 inches must be dealt with when hot under a strong hydraulic press. The operation of straightening bends requires the attention of a skilled and experienced mechanic to prevent the occurrence of distortion at other points during the process.

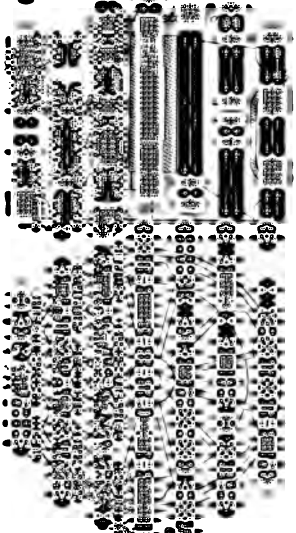
Webbing of Slide Passages, &c.—Whenever a cylinder is opened out, the webs of the slide ports and passages should be carefully examined to ascertain whether they are sound. The webs should be sounded with a light blow from a hammer. If a web is found to be cracked it may be necessary to fit a patch over the crack. This patch may be of steel plate; but in certain positions it may be better to fit a patch cast to shape, moulded from a previously fitted pattern, and carefully bedded in position. In all cases the patch itself and the securing bolts should be of sufficient size to restore the strength of the part injured by the crack. All bolts must be firmly secured. Steel screwed stays are now very generally used for strengthening steam passages and the slide valve face. Webs are made with a bulb along free edges, and these latter should not be straight but curved, so that there may be less danger of a slight flaw in the edge developing into a crack under the cooling, or subsequent, strains. Sometimes, instead of patching a crack, the strength may be made up by a steel bar stay fitted approximately at right angles to the line of the crack. In deciding on the way in which the repair is to be made, the run of the crack, the surroundings, and the apparent purpose for which the web was fitted, should be carefully considered. In some cases, it may be decided that the crack can be safely let alone, but a small hole should always be drilled at each end of the crack to prevent any extension. A sketch should be made of any crack, when discovered, for reference on future examinations.

Joints of Cylinder Liners.—To test these joints readily, take off the manhole doors of the cylinder and admit steam to the jacket only; if no steam issues from the manholes get inside the cylinder and examine the joint. It is necessary to dry out the bottom of the cylinder before beginning the test. In most high-pressure cylinders no manhole can be fitted in the bottom, but the steam test can be applied, and, if the liner is leaking, steam will issue from the indicator cock, if opened to the bottom end. If there is no manhole in the cylinder bottom, the piston must be withdrawn to remake a bottom liner joint. A considerable time is required to remake this joint, and the first opportunity may not occur before the periodical refit of the machinery is taken in hand. A mixture of red lead thickened with picked asbestos fibre is a good material to use for pressures up to 135 lbs. per sq. in. The joint should be tested by water pressure when dry. In the latest practice, with steam pressures as high as 250 lbs. per sq. in., the bottom liner joint is made by a continuous ring of soft metal fitted in a groove between the flanges.

When the indicator pipe is led through the side of the cylinder, a leak is often found where the pipe screws into the liner—especially after re-making or screwing up a bottom joint—owing to the fact that the liner has shifted relatively to the cylinder barrel. To overcome this difficulty annular plugs can be screwed into the cylinder and liner, and, in the event of a leak, the holes can be brought into line, tapped out larger, and a larger screwed pipe fitted. If often refitted, new plugs can be inserted and a fresh start made with the small size of pipe. The plug must be properly secured to prevent it working round so that it would project beyond the working surface.

Cylinder Mountings.—The sides, and sometimes the bottom, of a cylinder are covered with lagging, which must be partially removed in the event of a hidden leak; subsequently, when steaming, the leaky point can be localised. The joints of the cylinder manhole doors should be made with asbestos sheeting, if it will stand; this practice will save time and red lead during the frequent examinations. The studs of the lower door often rust quickly, especially if the neighbouring gland is leaky; and the same remark applies to the studs used for adjusting the gland.

The slide valve and cylinder valve face should be examined frequently. The surfaces should appear smooth and uniformly polished. During the examination the "lead" at each dead point of the crank, and the points of cut-off and admission on each stroke, should be ascertained. Before making these measurements see that the block in the independent arm on the weigh [illegible] over to full ahead, [illegible] equently; for this [illegible] webs should be [illegible] These webs are [illegible] x in Figs. 22, 23; [illegible] o make good the [illegible] webs of a slightly [illegible] the sketches, they



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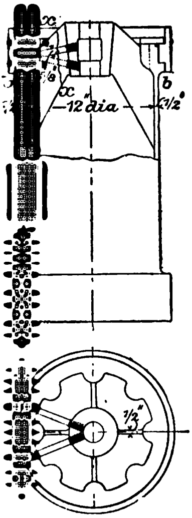


Fig. 23.

[illegible] elves to the expan- [illegible] temperature. The [illegible] orted or fractured, [illegible] some torpedo-boat [illegible] nze the rim can be [illegible] Fig. 24 illustrates [illegible] ratchet or spanner [illegible] those between the [illegible] piston slide valves [illegible] main and auxiliary [illegible] te of steam to the [illegible] he coal expenditure in harbour has been reduced by one-third by a general refit of the piston slide valves of the auxiliary engines.

To place the crank on the dead point, scribe a line on the piston-rod about ½ inch from the limit of the part which enters the gland; turn the engines ahead, and, when the scribed line enters the gland, chalk mark the tooth of the turning wheel which is opposite a convenient fixed mark. Then turn the engines ahead until the scribed line just emerges; mark the tooth on the turning wheel, which is now opposite the fixed mark selected; place a distinguishing mark on the tooth midway between those found; turn the engines astern, and then ahead, until the midway tooth is on the fixed point selected. The engine is then on the dead point.

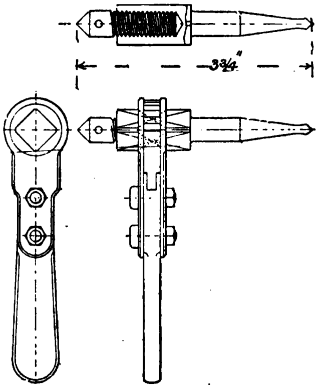


Fig. 24.

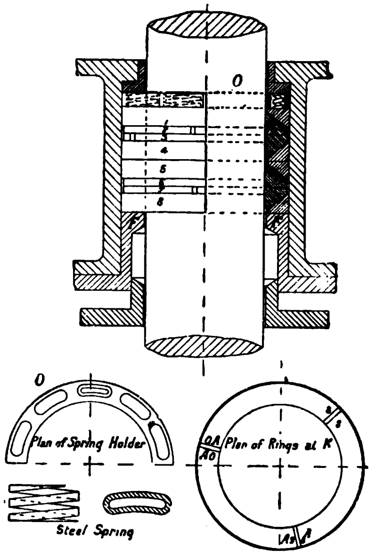


Fig. 25.—Combination Metallic Packing.

The engines must always be turning ahead when the marks come on; otherwise an error will be introduced by the backlash. The same process can be repeated for the other end of the stroke. If there is no turning wheel the method can be modified by scribing lines on a shaft coupling or flywheel.

If it is found, by comparison with the original setting of the valve, that the valve has dropped, it can be raised by inserting a liner between the valve and the collar on the slide rod, or by re-adjusting the bottom nuts, if so fitted;

or, as an alternative, a liner may be fitted on the eccentric strap under the foot of the eccentric-rod.

Relief Rings.—The pressure gauges fitted at the back of the relief ring will show whether the latter is efficient; but when the valve cover is taken off, an examination should be made of the relief-ring springs and of the rubbing surfaces; the latter must be kept very smooth.

The removal of the cover and the examination of a large slide valve is usually a matter of two to three days' work.

Glands of Piston and Slide-Valve Rods.—The glands of a high-pressure cylinder are now generally filled with some form of metallic packing, and, for the sake of uniformity, this arrangement may be used in the intermediate and low-pressure cylinder glands also. The metallic packing is secured by a box or cover, bolted home on the stuffing-box flange and forming a steam-tight joint. The neck bush and lower sliding plate under the metallic packing may be so fitted that the packing moves in the box with the rod, the necessary clearance being allowed. Double glands are very generally fitted in H.M. vessels. The inner gland contains the metallic packing, and the outer gland—containing two or three turns of soft packing—is formed on the cover of the inner gland, as in the arrangement (Fig. 25) made by the "Combination Packing Company," which is suitable for pressures up to 155 lbs. per square inch. Springs are fitted, as shown, to keep the bearing surfaces in contact. These springs should, when in position, be compressed—for white metal rings, $\frac{1}{4}$ inch; for yellow metal rings, $\frac{3}{16}$ inch. The highest number marked on the edge of the packing rings goes next to the gland, F, and so on to the lowest number. The spring holder, O, and springs are put in first, and go next the neck bush. The numbers on the edge of the packing rings should be placed in line. Each set of metallic packing has a distinguishing letter marked on each segment, and each of the different glands has its particular letter. When refitting the packing, the working rings will generally require easing at the butts, to enable them to close on the rod; this will reduce the total length of the packing, and it will be necessary to fit a liner at the bottom of the box, to obtain the necessary compression of the springs. In all cases, whether the packing be refitted or new rings are supplied, the overall length of the packing should be measured. The rings have lately been made in three segments tongued together, the butts of consecutive rings not forming a straight line; this pattern is thought to adapt itself to the rod closer when wearing. Fig. 26 shows a later type of the Combination Company's packing, named the "Floating Type." The parts are designed and fitted with clearances (marked A in the sketch) to allow of a small swaying motion of the rod without leakage of steam. The wear, as it occurs, is taken up by inserting an annular liner between the parts 12 and F, of a thickness selected, to give the springs the original compression.

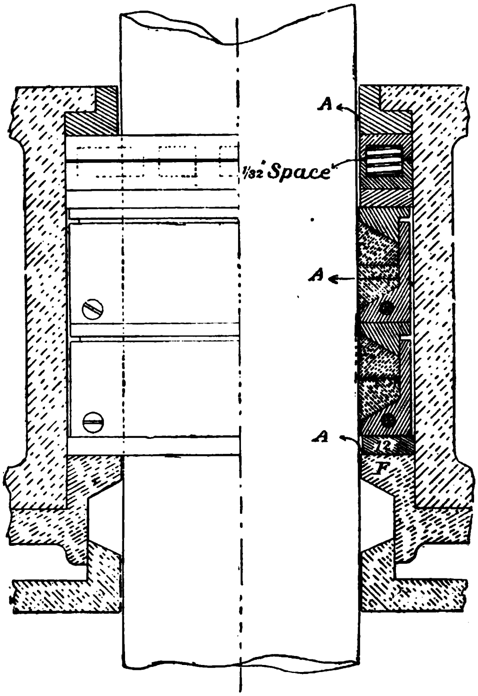
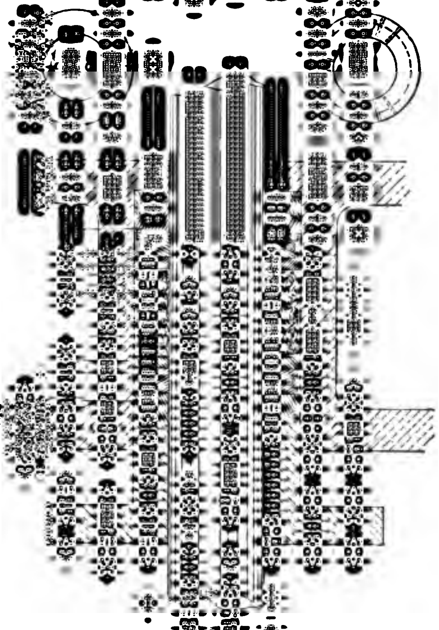


Fig. 26.

The packing illustrated in Fig. 27 has been found very suitable for the stuffing-boxes of piston-rods of fast-running auxiliary engines, such as those used for dynamos on board ship. The sketch shows the fittings necessary to adapt the stuffing-box of an 8-inch diameter rod designed for the use of soft packing, which latter did not prove satisfactory in practice.

a, *a* are gunmetal bushes made in two halves and fitted to the cone of the existing neck bushes and glands (these would be unnecessary if the existing bushes were flat). *b*, *b* are gunmetal rings made in three or more pieces, enveloped by a continuous [illegible] these rings, *b*, *b*, [illegible] of vulcanite, made [illegible] clear of the rod; [illegible] a mass of packing [illegible] king of a granular [illegible] 2 parts of black [illegible] on of 10 parts of [illegible] king is made in the



[illegible]

[illegible] canvas case, from [illegible] round stick. The [illegible] nd the rod and is [illegible] ing-box. Plans of [illegible] a different scale. [illegible] ches the rings, *b*, *b*, [illegible] he gland and neck [illegible]

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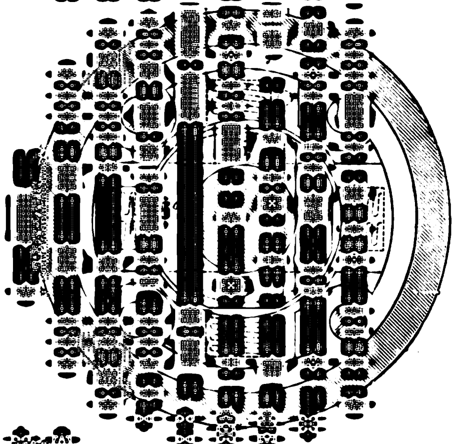

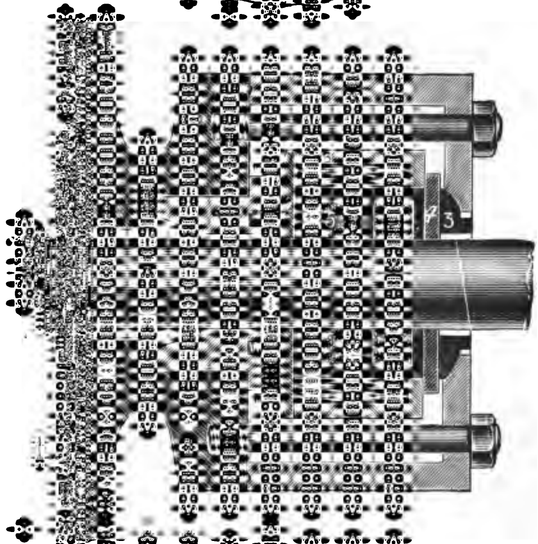

[illegible]'s Packing.

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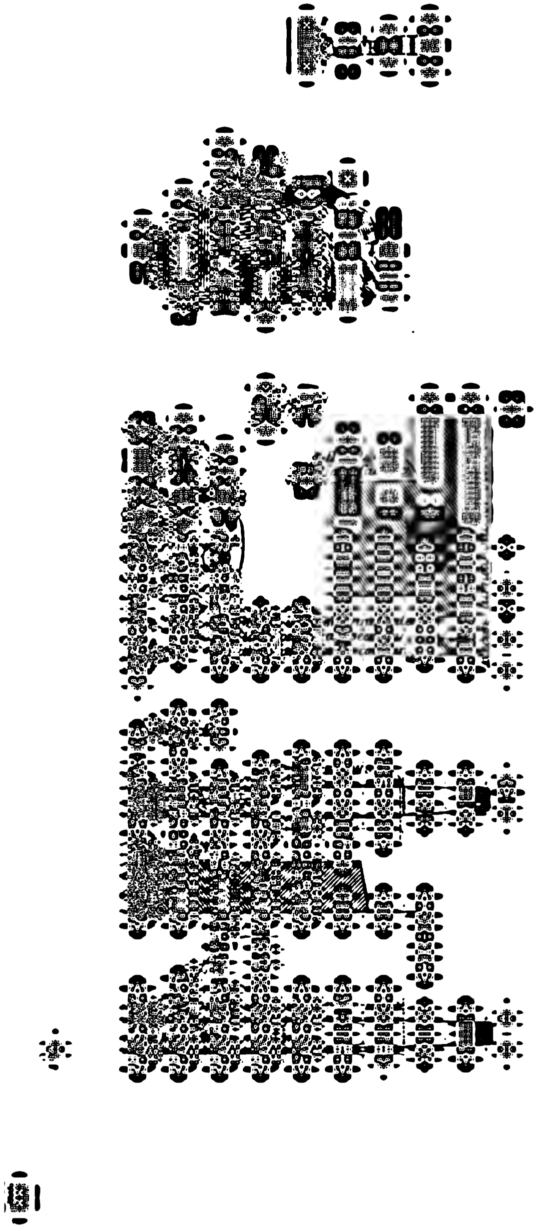

The composition of an efficient substitute for Belleville packing is given on p. 343.

The United States Company's packing shows another arrangement of metallic rings. In this case the metallic rings are contained in a box, which is bolted on outside the cylinder. This packing (Fig. 28) consists of eight blocks, "Babbett" lined, which are held in strong rings (6) having pockets or horns, holding springs (7). The packing blocks are put together in sections, four blocks to a section. Each section is composed of two working blocks (5) and two guide blocks (5*a*). The joints between the blocks in one section are at right angles to those in the other section, thus breaking joint. The blocks are regulated by springs, which merely keep the parts in place when the steam is shut off, as when steam is applied the steam pressure regulates and sets the packing. A ball joint (3) on one side, and follower (9) with springs on the other, give the packing free play and keep it steam-tight, thus annulling any swaying of the rod.

To pack a gland with soft packing, cut off a length rather longer than the circumference of the rod; angle the cuts so that the ends butt together tightly; place the "turn" around the rod, insert the loose ends first, and then drive it all in by the use of packing sticks. Asbestos packing will stand a higher temperature than that containing india-rubber, but is more pervious to water. Many valve glands are packed with alternate turns of asbestos and india-rubber core packing, a turn of asbestos being placed nearest the steam. The joints of the consecutive rings should not be in a direct line along the length of the rod or spindle. If, on examination, the packing in a gland is found to be hard it should be replaced by new turns.

Crank Shafts.—The following notes and sketches (Plate III.) are abstracted from a paper read by Mr. Manuel, superintendent engineer to the P. & O. Company (*Proceedings of Inst. of Naval Architects*, July, 1897):—

"Deterioration in crank shafts may be due to the oil for lubrication being squeezed out of the bearings, so that excessive friction is set up and hot bearings occur. Some of the bearing nuts may be slacked back, and salt water used for lubrication; the surface of the bearing then gets rough, the shaft is strained by alternate bending, and sudden cooling and heating; and, if the bad treatment is continued, the shaft gets out of line, fracture commences and continues until the shaft breaks.

"Cases of crank-pin bearings which required renewal after [illegible] were due to insuf-

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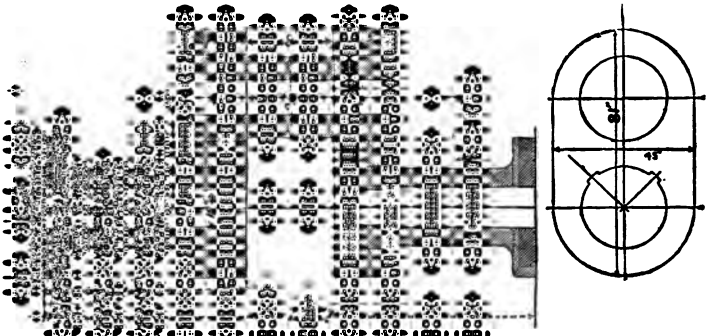

[illegible] of Rome."

[illegible] greatest strain, they
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[illegible] s, made on the open
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in this respect it was far superior to iron." Mr. Milton also said that he "attributed the improvement in the durability of shafts, not so much to the adoption of the three-crank engine, as to the increased use of built shafts; the masses of metal were smaller and more immediately under the control of the forgeman."

An example of a built-up shaft is shown in the illustration of that fitted in the "City of Rome" (Fig. 29). The weight of the three-throw shaft is 63 tons; it is made of fluid compressed steel, forged by hydraulic presses. The pins are shrunk in the webs; the webs are forged from ingots, the holes being punched and afterwards forged on mandrils; they are keyed as well as shrunk on the shafts. The amount allowed for shrinkage was $\frac{1}{1000}$ of the diameter.*

Propeller Shafting.—Mr. Manuel stated that "steel corrodes more quickly in sea water than iron; it must be protected from the sea water, and is then used with advantage. The best method of protection is to cover it with one length of gunmetal." In the sketches given, a method of jointing a gunmetal liner, which is fitted in more than one length, is shown.

Flaws frequently develop around the shaft at the extremity of the gun-metal liner, and may be caused by corrosion (see Fig. 9, Plate III.).

Mr. Milton pointed out that "where a gun-metal liner was shrunk on, a rigid point was obtained, and the greater strain came just at the end of the liner. This led to the suggestion that liners should be made longer and tapered down until they were as thin as would enable them to be kept tight. In that case, if corrosion took place between the iron and metal, it was possible to cut a piece of the liner and so remove the liability of damage to another place. Failures of shafts were due to the way in which they were used. Tramp steamers often went to sea so light that their propellers were half out of water. This led to the blades giving a blow each time they entered the water, and it was the concussion thus caused that was hard on the shafting; it was in steamers of this kind that the greatest number of failures were found."

Mr. Holt, agreeing with Mr. Milton, said that twenty-three vessels in the N. Atlantic alone, broke their tail shafts last winter.

Mr. Mudd said that 90 per cent. of the shaft accidents occurred to tail shafts. The galvanic action between the iron and brass cuts a fine nick, and the straining forces act at that point.

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* The common practice, for shrinking in the pins of connecting-rods, &c., is to bore the hole from two- to three-thousandths of an inch smaller than the pin for all sizes. The annular part is then heated to just below a blood red, when the hole should be $\frac{1}{32}$ of an inch large. The pin can then be forced home without risk of seizing. The same practice is followed in fitting the gunmetal sleeves on steel shafts.

The practice in the Royal Navy is to fit a gunmetal casing over the shaft in the stern tube and also over the part in the A frame, the latter casing is continued to enter the propeller boss; and these bearings are bushed and lined with lignum vitæ. In the destroyers, no casings are fitted; and the bushed bearings are lined with white metal. Exposed shafts are, in all cases, well painted with red lead outside the bearings. Water is prevented from entering the propeller boss by a shallow stuffing-box formed around the shaft, into which a gland is fitted, made in two halves bolted together when in place.

The method of examining shafts for flaws or cracks with a microscope is recommended. The extent of a crack can be estimated by tapping the shaft with a hammer, to expel the oil or water collected in the crack. When a crack is discovered a centre pop mark is made at each end to determine at subsequent inspections whether the crack is extending.

Crank shafts for large triple expansion engines in the Royal Navy are made in three or four interchangeable lengths, so that if a crack or flaw developed in the after length it could be transferred to the forward engine, where it would be subjected to less strain. Temporary repairs have been carried out on board to enable the ship to make port with a damaged crank-shaft.

If the flaw extends across the web, as shown in the side elevation (Fig. 1, Plate III.), a strap is fitted right round the web and is drawn tight by bolts placed through flanges in the strap situated at one end of the arm. In the case of an auxiliary engine, the strap is welded and is shrunk around the arm.

If the flaw is in the crank pin, a bolt can be run through the length of the pin if the latter is hollow.

If the flaw is at the junction of one arm and the shaft, feathers are let into slots, cut across the break, at the surface and running parallel to the axis of the shaft; the feathers are secured to the shaft by countersunk screws. A similar plan is followed if the shaft breaks in the screw alley between two bearings, but then the feathers are secured by straps, running around the shaft and drawn tight by bolts through suitable flanges.

Whenever such a repair has to be made, due regard must be paid to the nature of the straining actions to which the broken part and the temporary fittings are subjected. It is obvious that the engines must be run at a reduced speed so that the stresses to be resisted are proportional to the strength of the temporary connections. Such temporary fittings should not be regarded as merely keeping two parts together, but should be so placed as best to resist the stresses to be transmitted.

Alignment of Shafting.—As part of the complete refit or thorough repair of a ship's machinery, it is necessary to test the alignment of the shaft bearings, from the forward main bearing of the crank shaft to the bearing in the bush of the A frame, right aft, with a view to decide which bearings, if any, require remetalling.

The method to be employed may be chosen from those described later, and will depend on the amount of wear observed in such bearings as may be withdrawn for examination, and, further, upon the time and money at disposal.

The preliminary observations to be made include measurements of the wear down—that is, of the clearances above the shaft journals in the bushes of the stern tube and A frame, and also of the thickness of wood or white metal to be worn down before the shaft touches the metal of the bushes. From a comparison of these two sets of measurements with each other, and with those made from time to time since the bearings were last lined up, it can be decided whether new wood or metal is required. It will not generally be necessary to renew the wood, even at the commencement of a three-year commission, should the thickness still to wear be distinctly greater than the clearance space above the journal. It should be here remarked that the white metal in the bushes of the stern tubes and A frames of torpedo boat destroyers are usually refilled when the wear down is equal to the thickness of metal still left to wear. The clearance allowed is $\frac{25}{1000}$ inch.

If it is decided that the stern bushes contain sufficient wood, but that the plummer blocks and main bearings need new metal, then Method I. can be employed, which is as follows:—

Method I.—The bolts are withdrawn from all the couplings on the shaft forward of the stern tube, and the tail shaft is drawn aft a few inches, so that each of the pairs of couplings can be opened sufficiently to clear the spigot; the brasses are all removed from the frames and the various lengths of shaft are supported by liners placed on the frames, and are then adjusted so that the faces of the couplings come exactly fair; each length of shaft, beginning from aft, being raised or tilted until the circumferences of each pair of couplings are fair and the clearance between the faces is exactly the same all round the circumference. This adjustment can be made with great exactness by means of "feelers." The various couplings from aft to forward having thus been faired up, the requisite thickness of metal for each brass can be gauged, and the brasses can be refilled with white metal and bored to correspond with the gauge. Should the thickness of white metal in the forward main bearing brasses, so determined, be considered insufficient, the forward end of the shaft in the stern tube must be slightly raised in order to obtain a more suitable line of bearing. If the ship possesses gauges, as shown in Fig. 30, to determine the original position of the shaft, the proper thickness of white metal can be more readily checked.

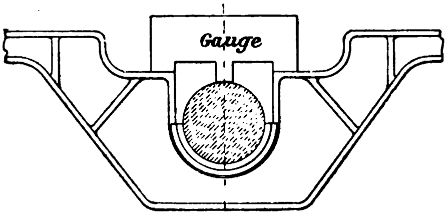

Fig. 30.

Method II.—Should the wood in the stern tube and A frame be badly worn,* as also the metal in the plummer blocks and main bearings, it may be considered necessary to sight through all the bearings, as was done when the engine was first erected in place. To carry out this operation the ship must be placed in dry dock, as it is necessary to completely remove all the shafting, both forward and aft of the stern tube, from its bearings; the blades of the propeller are taken off, and the shafting outside the stern tube and the propeller boss are rested on a temporary timber framework erected in the dock.

The removal of the tail shaft is facilitated if the bushes in the A frame and stern tube are removed first, as the tail shaft can then be deflected from the line and drawn forward.

The removal of the loose coupling just forward of the stern tube is generally an operation of some difficulty, as it is frequently found tightly seized, and must be well heated before it can be removed. For this purpose a giant torch or similar petroleum lamp is useful. The keys in the loose coupling are removed with the coupling by means of a bolt with a fine thread screwed into a hole drilled in each key and secured to a plate overlapping the face of the coupling. If the key fits too tightly, one or two holes drilled right through its length will often serve to loosen it. The coupling itself is removed by stout bolts screwed with a fine thread and rove through the holes in the coupling and through corresponding holes in a thick circular strongback plate pressing against the end of the shaft; the nuts used on the bolts should be 1½ or 2 diameters in depth. Should the coupling not move under this treatment it must be further heated and longer bolts inserted, so that a hydraulic jack can be used, placed between the strongback and the end of the tail shaft. If these means fail, the coupling must be split in two halves by drilling a line of holes across a diameter.

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* The clearance allowed is $\frac{3}{1000}$ of the diameter of the shaft.

Before the crank shaft and thrust shaft and collars are removed the position of the crank shaft and thrust shaft in a fore and aft direction must be carefully marked so that they can readily be replaced in their proper position, and so facilitate the replacement and adjustment of the connecting-rod brasses. If the thrust collars are re-metalled their position will be modified slightly. The shafting and brasses being removed, stout wooden screens with a 2-inch hole are fitted up in the main bearing frames, and in those of the stern tube and A frame. These screens carry a sighting appliance, as shown in detail in Fig. 31, secured to the screen over the hole in its centre. This appliance consists of a frame carrying two pairs of sliding shutters, which latter can be moved in directions at right angles to each other by means of the adjusting screws. When picking up the line of sight these shutters are run in until the aperture is about $\frac{1}{32}$ inch square. When the screens are fitted up a candle, or, preferably, an incandescent electric lamp, enclosed in a box with a parabolic reflector behind the light, is placed in front of and in a line with the foremost sight in the engine-room, at the point A shown in Fig. 32; the other sights are brought on by sighting through the eyepiece shown in Fig. 33, which is attached to the aftermost sight hole

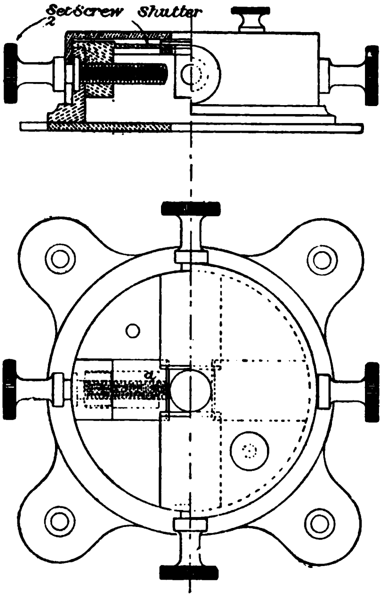


Fig. 31.

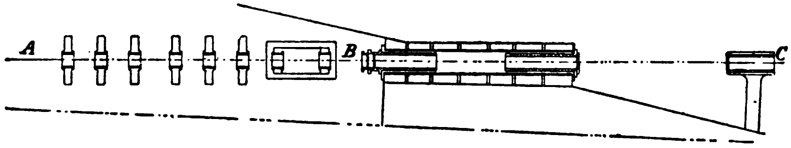


Fig. 32.

in the A frame at C. This eyepiece very much lessens the fatigue to the eye and the difficulty experienced in picking up the line. It is necessary to perform the operation of sighting at night, with a canvas screen or tunnel rigged up around the line of sights outside the ship to exclude any external and confusing source of light.

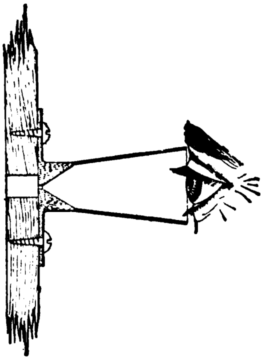


Fig. 33.

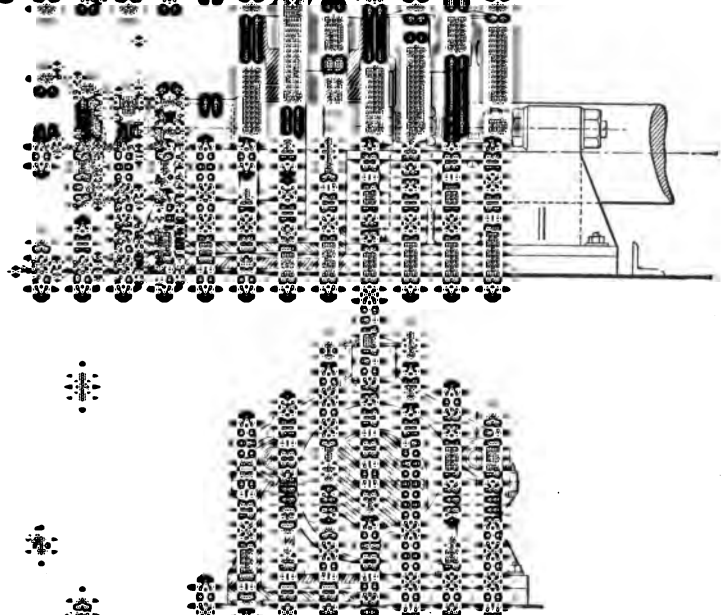
The sighting appliances having been fixed, the most suitable alignment is determined as follows:—The first point fixed in the line is the centre of the stern bush at its foremost end, B (Fig. 32); this point must be determined so that the stern gland will enter freely; the next consideration is that the line chosen shall suit the seating of the brasses in the foremost main frame, and also the bore of the A frame, which holds the removable bush; to this end the line of sight must be tilted about the point B as a pivot until the divergences from the natural centres of the seatings at the ends A and C are equal.

The best line having been thus determined, intermediate points in each bearing can be picked up separately, and the measuring circle needed to determine the thickness of each brass or bush is scribed on the frame from the centre so found. It will be found convenient to have not more than three or four small apertures in line at one time, in order to reduce the difficulty of picking up the line of light.

The brasses should be sent to the shop to be remetalled when they are withdrawn, and separate gauges for each can be made from the data given by the circle scribed on each frame; it is usual to stretch a wire through the centres of the crank-shaft main bearings for reference throughout the operation of boring the brasses.

The wood strips in the bushes of the stern tube and A frame having been renewed, the bushes can be bored out, either in place by means of a boring bar, driven by a small portable engine and set from the data of the scribed circles, or in the shop if more convenient.

After the brasses of the main bearings have been replaced, the shafting is bedded, for which purpose it must be lifted in and out of the bearings some three or four times until a proper marking is obtained by scraping the hard places made on [illegible] are scraped up and [illegible], as given on p. 106. [illegible] isable to extend the [illegible] not so made origin- [illegible] with the coupling [illegible] ad for withdrawing [illegible] e process of fitting; [illegible] inch of their length [illegible] er. Any slackness [illegible] on service, and give [illegible] afting and coupling [illegible] shafting should be [illegible] opportunity.



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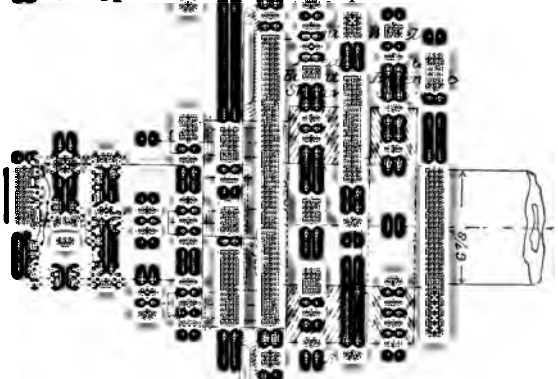
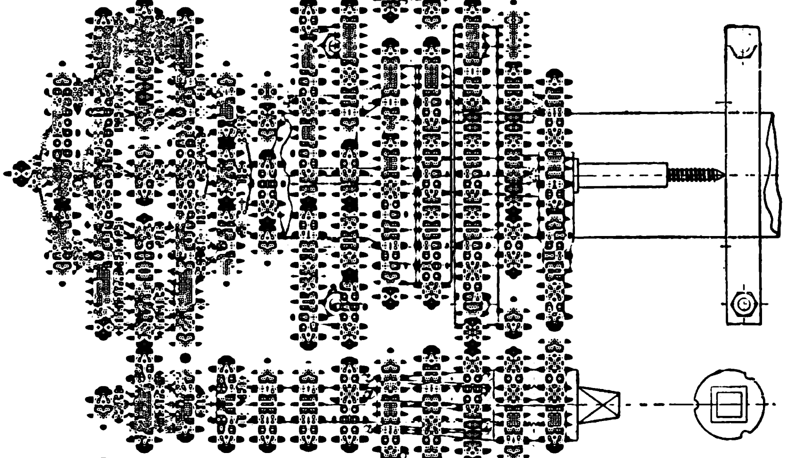
[illegible] ost common form of [illegible] which each collar is a [illegible] d over the shaft and [illegible] gs, one on each side [illegible] d aft screws, carried [illegible] with nuts which are screwed up against each side of the lug; each separate collar can thus be independently adjusted if it works warm. The clearance of the collars should be $\frac{4}{1000}$ to $\frac{8}{1000}$ of an inch when the white metal is renewed. Means are also provided for shifting all the collars together. The thrust of the propellers, being transmitted by the shaft collars to the thrust collars, causes the latter to wear in course of time, and the whole of the shafting may shift forward. If such a shift has occurred it will be detected by the bright ring on the forward side of the propeller shaft bearings. Marks should be scribed around the circumference of a new shaft to furnish an indication of any future shift of position, and a gauge should be provided to show the original distance from some mark made on a fixed part such as the main bearing frame. A little clearance, about $\frac{1}{8}$ inch, is sometimes allowed between the couplings of the propeller and crank shafting, but if the wear in the block exceeds this amount the crank shaft will be thrust forward and the crank-pin bearings may be thrown out of line. In such a case it is necessary to set the thrust block aft, bodily, by means of the screws fitted for the purpose. Any such adjustment must be done cautiously, as hot bearings may result from the displacement of grooves worn on the journals. If the crank shaft has been thrust forward, the clearance on the after side of all the crank-pin bearings will disappear, and the after crank arms may be found rubbing against the crank-pin brasses (see p. 115).

All coupling bolts must be withdrawn and cleaned, from time to time, to prevent seizing; those connecting the crank and propeller shafting are examined about once a quarter. Wrought-iron nuts are fitted to large steel bolts to prevent seizing.

Fig. 35 illustrates a defect which occurred to the coupling bolts of the crank and propeller shafting of a torpedo boat destroyer. The bolts, six in number, were found sharply sheared across the sections *x x*. The loose ends of the bolts were prevented from working out by the proximity of the eccentric sheave, E, and the coupling continued to drive the propeller shafting until the first occasion of working the engines full speed astern, when the propeller shaft coupling drew clear and left the engines free to race. The bolt holes were found about $\frac{6}{1000}$ inch oval; and, as is well known, any looseness of fit of coupling bolts rapidly leads to serious defects. Fig. 36 illustrates the tool and method employed to broach out the holes for coupling bolts. This operation should always be done with the shafts in place to ensure the accuracy of the line through the two couplings. The cutting edges of the rimer are shown at *a a*, and the tool should be revolved in such a direction that it does not draw into the job. The bolts of the rigid couplings on crank and [illegible] lly ; they should [illegible] heavy hammer for [illegible]





[illegible] ser need cleaning [illegible] gh the tubes they [illegible] the steam passes [illegible] a solution of soda in fresh water, which may be heated. After using soda in a condenser the interior must be thoroughly washed out to prevent any trace of the soapy matter formed entering the boiler.

Periodical examinations are made by taking off the manhole and handhole doors, for the purpose of clearing out the grease deposited in the space provided for the condensed steam, and to examine the zincs and tubes. Zincs are fitted in the condenser to arrest corrosion of the tubes, or of the metal of the condenser, set up by galvanic action. Those immersed in salt water have the shortest life, and must be frequently renewed. The material of the tubes and condenser shell should be the same. The Admiralty specify 70 per cent. Cu, 29 per cent. Zn, and 1 per cent. Sn for the composition of the brass used. Condensers are sometimes, for economy, made of cast iron, but sea water destroys this material in time, and renders it soft and spongy, so that, in some cases, the metal can be dug out with a knife. The zincs are secured, as in boilers, in the form of plates; they are also fitted in the form of rods. The method in the latter case is to provide screwed brass plugs into which the zinc rods are soldered. The plugs are screwed into certain of the holes for the tube glands, and are distributed over the surface of the tube plates. The plugs are provided with a square head for a spanner, and the rods project inwards along the length of the tubes. These rods must be frequently renewed. Of late, mild steel plates and rods have been used in lieu of zinc.

Opening Out.—Before opening out the fresh water side of a condenser, it should be pumped out by whatever means is provided for that purpose, and a certain amount of fresh water is thus saved. It is necessary to observe the precaution of airing a condenser after it is opened out, because the action of the water and zincs liberates hydrogen gas, and if a light is introduced for examination of the interior before the hydrogen has escaped, an explosion will occur.

The tube glands are packed with tape soaked in hot tallow, or in linseed oil; they need screwing up from time to time to prevent leakage.

Tests for Leaks.*—The tubes of a condenser are liable to split; also, in spite of the zincs, the material is frequently pitted by corrosion, and pinholes are formed.† A very slight leak in the tubes of a condenser will, by accumulation, cause the water in the boilers to be salted, and to show a density; therefore the examinations of the tubes must be carefully conducted. The method employed to examine the tubes depends on whether the salt water passes through or around them. If the salt water passes around the tubes, and the latter are vertical, the examination is easy. Take off the manhole doors at the top and bottom, giving access to the steam and fresh-water spaces. Leave the salt-water space in communication with the sea. After a short interval, introduce a light under the tubes, dry up the spaces, and look for drips from the tubes. Taste the drops of water as they fall; it is necessary to keep the top tube plate dry to find the leaky tube; otherwise, if the top glands leak, the salt water may run down a sound tube, because it is lower than the others. If salt water is running down a tube and the glands are tight it may be inferred that there is a leak in the tube. The practice in such a case is to drive a turned conical plug of soft white wood into both ends of the tube. The tube is identified at the top tube plate by passing a long wire through from the bottom. It generally happens that corrosion attacks a group of tubes, and, in some cases, 10 per cent. of the tubes may be so plugged before an opportunity occurs of replacing them by sound ones. Whenever a number of tubes have been corroded, it will be best to withdraw the whole for a thorough examination or renewal, and to test them under pressure singly.

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* The cold drawing process when used in the manufacture of brass tubes leaves them hard; they should be annealed afterwards by placing them in a bath of molten lead for a few minutes; after withdrawal, they should be allowed to cool slowly.

† A recent Admiralty order directs that air pipes of 1 to 2 inches in diameter, should be fitted to condensers, to discharge the air carried in the circulating water. They are to be led above the water line from the highest part of the condenser.

If the salt water passes through the tubes, shut the main inlet and outlet valves tightly, and rig the outside plugs on the ship's side over the outlet orifices. Drain the condenser of fresh water. Shut off all gauge glasses and vacuum gauges. Blank flange the pipes communicating with the low-pressure cylinder and air pump, and also, if necessary, any drain pipes from the cylinders and from steam and exhaust pipes which are led to the fresh water side. Fill up the space around the tubes with salt water by a hose inserted before the blank flange is put on the inlet for exhaust steam. A cock must be introduced in this blank flange leading, by a copper pipe, to a test pump, by means of which a pressure not exceeding 30 lbs. per square inch is put on the condenser. The interior of the condenser being under pressure, the tube plates are carefully dried, and the ends of the tubes examined for salt-water leaks. The first proceeding should be to screw up the slack glands. There is sometimes difficulty in detecting a leaky tube, because the water pressure, being applied outside the tube, tends to close up openings, whereas under working conditions the salt water is drawn through from the inside by the outside vacuum, and any rents are opened out. In such a case, all the tubes may have to be withdrawn and subjected individually to a water pressure applied internally. The author has experienced such a necessity, and, in the case of H.M.S. "Hebe," the condensers were proved to leak under steam, though when the condensers were cold and subjected to a water pressure no leak could be detected. It may happen that the leak occurs, not through the tubes but under the bolt heads securing the stays between the tube plates. It is advisable to withdraw the packing from the glands of a number of tubes to ascertain whether it is perished. If a jet of steam is discharged on to the tubes from a drain pipe, or through the eduction pipe, it may cause them to chafe, and the jet of steam itself may wear holes in the tubes, so that leaks are caused. To prevent such action, baffle plates should be fitted to distribute the steam delivered, and to take the momentum of the impact; the tubes should be a close fit in the intermediate diaphragm plates in order to prevent chafing.* Such internal surfaces of a condenser as are exposed to sea water should be coated with a thin wash of Portland cement at each examination. If the usual waste of fresh water is suddenly diminished in quantity there is good reason to suspect a salt-water leak to the boilers, and the density of the feed-water should be immediately taken. The author adopted the plan of boiling away five-sixths of the water drawn off from the feed tank, before taking the density, in order to magnify the effect of a slight leak of salt water, which might otherwise escape detection by the hydrometer.

When condenser tubes are withdrawn for cleaning or testing they may be found heavily coated with salt. If the salt is on the outside it may be removed easily by boiling the tubes in a solution of caustic potash, to remove all grease, and then immersing them in muriatic acid, after which they should be scoured with sand and well washed with fresh water to remove traces of acid. If the salt is inside the tubes it will generally be cheaper and more expeditious to renew the tubes and chop up the old ones as old metal.

In re-tubing a condenser it is of the greatest importance to use cotton tape gromets made of the exact length of the stuffing-box and of a good fit around the tube and in the hole, the amount of screwing up can then more easily be judged from the level appearance of the glands in place. The inside end of the glands should not be bevelled, but should be left square;

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* The holes in the diaphragm plate should be fitted with wooden ferrules around the tubes.

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[illegible] ket valves are ex- [illegible] first opportunity

[illegible] Valve.

[illegible] y tend to become [illegible] lack greasy paste, [illegible] wasted zinc plates:

apparently the same deposit that is found around the water line of boilers.

India-rubber valves swell and become concave; they need trimming after being in use. If the edges are cut back and the valve turned over, the rubber is serviceable until it becomes soft and flabby. The grease can be removed by washing with hot soda solution. Templates of tin are made of the different patterns of valves, for the storekeeper's use. When a new supply is required, brown paper patterns are cut from the template and forwarded to the makers.

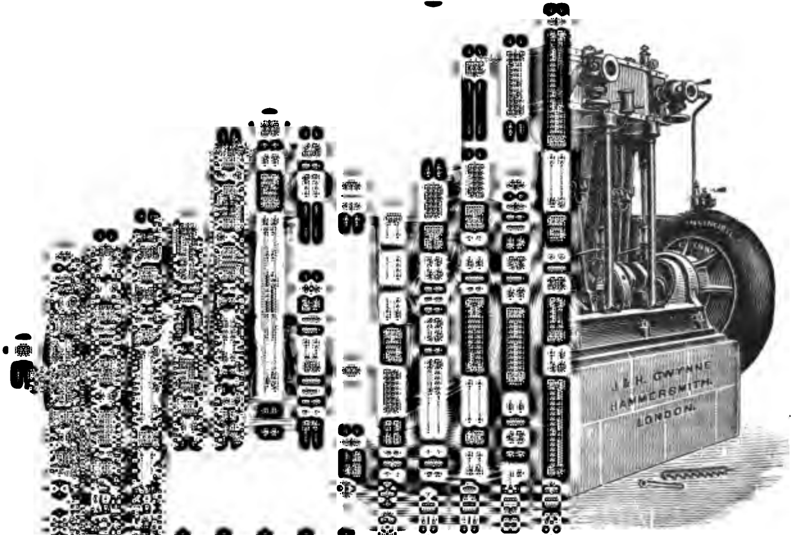
Metallic valves are often used for the air pump; they are formed of thin metal with either a flat or a corrugated surface (Fig. 37), and are more generally used for the air pumps of auxiliary condensers.

The plunger of an air pump is often packed with gasket, made of spun yarn plaited to a suitable thickness. One end of the gasket is jammed into a suitable hole, and, after being coiled in the packing space around the plunger, the loose end is sewn down. This form of packing is very serviceable if the speed of the plunger is not too high. When the gasket is worn out it can be picked to pieces by the fingers; it should be soaked in linseed oil from time to time. If the packing ring is of gun-metal and becomes too loose in the barrel, it can be made temporarily serviceable by opening it out with a wooden mallet.

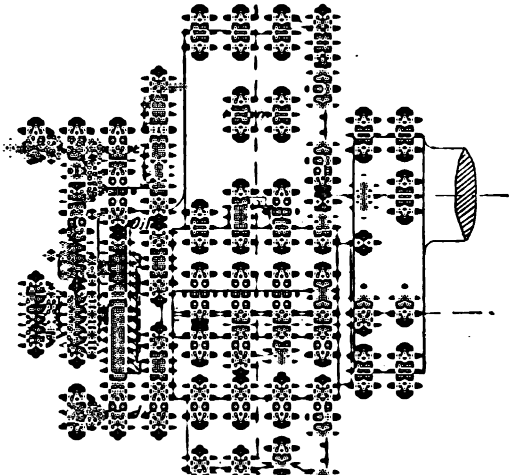
The glands of the air-pump rods are generally packed with gasket; if they are leaking the flame of a lamp will betray the fact, as will also the hissing noise made by the in-drawn air. The cups of the rod glands are sometimes filled with tallow, but it should be supplied in moderation as it has a most injurious effect on the boilers.

The Circulating Engine and Pump.—These are generally vertical, inverted, direct-acting, single-cylinder engines, driving a centrifugal pump (Fig. 38), and supplied by steam from the auxiliary steam pipe.

There is often an end thrust on the engine shafting, together with a disposition to wear down so that the clearance of the fan is destroyed on one side; consequently, one crank cheek may rub against a main bearing and cause overheating. To remedy this defect a small iron bracket may be bolted to the framing, carrying a brass plate which bears against the end of the shaft (Fig. 39). The brass plate is held against the end of the shaft by a set screw in the bracket, and is prevented from revolving by a stop. The lubricant can be supplied through an oil hole led to the centre of the brass plate, and distributed over its surface



[illegible] Gwynne's Centrifugal [illegible] Pumps.



[illegible] Bottom.

by a groove cut across a diameter of the shaft end. This device will often improve the running of auxiliary engines, the axis of whose shafting is not quite horizontal.

Choking of Passages.—The principal difficulty in the maintenance of the circulating pump is caused by the inlet passage valve, or grating becoming choked with seaweed or jelly fish. In one case the author has seen about 12 ft. of pipe between the pump and valve almost completely choked by a growth of mussels, which extended even into the pump chambers; and this pump had been in continuous use. **Weed boxes** are fitted to arrest seaweed, &c.; they are placed in an accessible position between the inlet valve and pump, and are formed by a grating, enclosed in a box with a cover secured by hinged bolts and butterfly nuts. If the inlet and outlet valves be shut, the weed box can be speedily cleared. Centrifugal pumps are often arranged so that the discharge from one can be used to wash out the suction of the other. For the same purpose a connection may be made from the delivery of the fire engine pumps into the centrifugal pump suction pipe. Since the weed is always moving aft relatively to the ship, the bars of outside gratings should run fore and aft, and if vertical stiffening bars are needed they should be sloped with the forward edge inboard; if possible, webs should be dispensed with in the case of inlet valves, nor should the centre spindle of the valve be guided through webs attached to the sides of the valve box, but should be carried into a guide piece in the bottom, since any obstruction in the water channel tends to accumulate weed, &c.

It is necessary to pay a good deal of attention to the auxiliary condenser when the ship is anchored in water infested with jelly fish, otherwise in a very few minutes the condenser may become overheated through the inlet choking. In such an event, if no weed box or other remedy is available, it is necessary to divert the exhaust steam from the condenser and to close the inlet and outlet valves tightly, after which a length of suction pipe must be rapidly removed. If the inlet valve be then suddenly opened, and again closed, the obstruction may be washed through the outside grating into the bilge, or into a bucket or sieve held to catch the jelly fish.

Steam pipes are subject to constant expansion and contraction caused by changes of temperature. In long lengths of pipe, expansion stuffing-boxes are so fitted that the pipe is left free to expand or contract. The packing in these stuffing-boxes must be examined from time to time, and renewed if it has become hard, to prevent the pipe seizing in the gland. Very frequently, however, the changes of length are taken up by the bends in a pipe, which is subjected to a continually alternating bending action at such places. It is under these circumstances that rents will develop in a copper pipe; the material becomes hardened and loses its elasticity, so that a small initial flaw will become gradually enlarged until a rent is produced. Copper steam pipes are often locally weak at bends, owing to the method of manufacture. A bent pipe is worked up from two flat pieces of plate and is generally not of uniform thickness when shaped. To counteract the hardening, caused by the working conditions, bends and bellows joints should be annealed from time to time. Mr. Milton * makes the following remarks on the process of annealing:—"In tube works the pipes are uniformly heated over the whole of their length, care being taken that the flame is clear and contains an excess of oxygen. In the coppersmith's shop, both sheets and pipes are heated over open coke fires; the flame may possibly be reducing—that is, may have a deficiency of oxygen, if the fire is a thick one. Oxygen is required to give ductility. The sheet or pipe is moved about over the fire, spot after spot being heated, generally to a dull red; and, after the whole surface has been thus treated, the copper is either quenched or allowed to cool, and is considered to be annealed. It thus depends on the workman's care and judgment to insure that every part has been heated, and there is considerable probability that some small part may escape full heating. Further, the heating cannot be uniform, nor can any part in general be retained at the red heat for any considerable time, nor is the temperature at any part raised to the same degree as is usual in tube works."

It appears that to properly anneal a copper plate or pipe it should be uniformly heated to a temperature of about 1000° F.; that is, beyond a red heat, and should then be allowed to cool slowly.

The greater number of accidents producing burst copper pipes appear to be due to the presence of a quantity of water in the pipe at the time that steam was admitted to it. Mr. Milton mentions fifteen cases, from that of the "Erin" in 1888 to that of the "Astrakhan" in 1893. Of these, seven were attributed to the presence of water in the pipe when the steam was turned on, and three to insufficient or defective arrangements for expansion.

Mr. Milton recommends that the water should be drained from steam pipes by automatic traps.

A plan has been described, in the routine for raising steam,

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* *Proceedings of Inst. of Naval Architects*, April, 1895.

in which the water in the main steam pipes is drained into the boilers. Before turning on steam to a section of pipe, all drains should be opened, and the stop valve just eased off its seating so that a leak of steam passes and will serve to warm the piping gradually, and expel the water. If, on opening out, the loud and alarming noise, caused by the hammering of a column of water be heard, the stop valve should be immediately closed and a further interval allowed for the drains to clear the pipe.

The source of a leak in a steam pipe should be located and repaired immediately it is noticed, to prevent a small flaw developing and, perhaps, occasioning a dangerous accident.

Copper steam pipes, for steam of 155 lbs. per square inch (gauge), are generally wound with wire to strengthen them. The wire is wound on under tension; if it is wound three strands at once, time is saved, and in the event of one strand giving way, there are still two to be relied upon. The ends of the wire are brazed to the pipe.

The steam pipes of the later (1902) warships are made of solid drawn steel in diameters from 4 inches to 10 inches. These pipes are subjected by the manufacturers to a test pressure of 1250 lbs. per square inch. The flanges are drawn on by hydraulic pressure, and have deep neck pieces round which a row of chain rivetting is placed, securing pipe and flange together. The joints between flanges along these pipes, were at one time made by jointless copper rings of triangular or other suitable section turned off a solid drawn copper pipe by the parting tool. The ring was kept in position by the circle of bolts around it; the joints so formed proved steam-tight, under pressures of 300 lbs., for large and small pipes alike.

Experience has shown that the use of these copper rings leads to corrosion of the flanges; the water which lodges between the flanges above the lower part of the circumference of the ring produces pitting in a circular groove, and after some years' service, on refitting the steam pipes, it has been necessary to face up the flanges in a lathe. This method of making joints is now superseded. In later practice the joints of steel steam pipes are made by facing the flanges on a surface plate; the faced surfaces are then painted with thin red lead and are drawn closely into contact. It is obvious that if such a joint does leak the quantity of water lost must be much less than in the case of a leaky ring joint, on account of the reduction of space between the flanges. These flanges are generally faced to leave an opening of upwards of $\frac{1}{16}$ inch at the outer circumference, as shown in Fig. 40.

A cheaper method of jointing steel-pipe flanges is by taking a cut across the face of the flanges in a lathe, using a V-shaped tool and a $\frac{1}{32}$ inch feed, the cut being of sufficient depth to bring the serrations up to a fine edge. The flange is then faced back from zero at points on the circumference lying $\frac{1}{4}$ inch inside the bolt holes up to $\frac{1}{32}$ inch, or more, at the outer circumference, as shown in Fig. 40. The serrated faces are then painted with thin red lead and the flanges are drawn together to crush the ridges of the butting faces one on the other.

It sometimes happens after some years' service that the lower internal surface of horizontal steel steam pipes are found pitted along their length in consequence of the lodgment of water due to incomplete drainage. In many cases it is possible to turn the pipes through 180°, so that the lower surface becomes the upper; the corrosion is thus arrested, and the life of the steam pipe is extended.

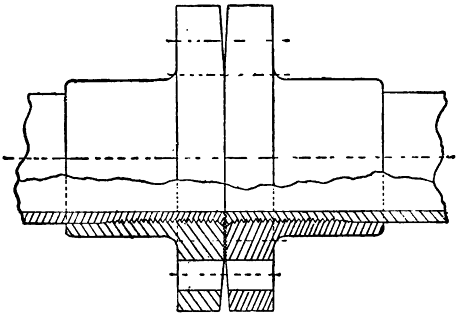

Fig. 40.

The Admiralty specify that the welds of steel steam pipes for the ships now building are to be covered with a rivetted butt strap, $\frac{1}{16}$ inch thicker than the metal of the pipe, the rivets to be kept well clear of the weld. The tensile strength of the acid open-hearth steel is to be between 24 and 27 tons per square inch. Each pipe is to be tested by an internal water pressure, before electro-zincing, to three times the boiler pressure, without showing any signs of leakage or porosity. This test to take place after the flanges are fitted and the pipes are finished. These pipes are zinced externally by electro-deposition after being pickled.

Professor Arnold* has examined the composition of the brazing of the flanges and joints of a number of copper steam pipes which have been some time in use. He found in certain cases that the zinc was dissolved to a greater or less extent, probably by the action of fatty acids. As an instance, an analysis of a certain brazing, originally consisting of half zinc and half copper, gave the following result:—Metallic copper, 0·768; zinc oxide, 0·224; fatty acid, 0·014—total, 1·006. In such a case the brazing, after some time, consists of copper in a cellular mass, the cells being filled with acid, and the percentage of copper present being far more than in the original spelter, owing to the destruction of the zinc.

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* *Electrical Review*, May 27, 1898.

List of Vessels in which Inquiries have been held by the Board of Trade as to the Cause of Casualties to Steam Pipes of British Vessels since the Case of the S.S. "Elbe" in 1887 (*Milton*).

Name of Vessel.	Date of Casualty.	Casualty, Cause, &c.
Erin, ...	1888	Wrought-iron pipe, connecting top of water gauge to boiler, corroded and burst. The pipe was apparently twenty years old.
Bryn Glas, . .	1888	Intermediate stop valve cover broke, attributed to the wheel for opening the valve being turned the wrong way.
Springbok, . .	1890	Main steam pipe of copper, 6 ins. diameter, $\frac{3}{16}$ ins. thick, broke away from the flange next the boiler stop valve, due to faulty construction and to imperfect repairs.
Jumna, . . .	1890	Main steam pipe of copper burst at the lap in a bent portion near the boiler stop valve, probably due to defective workmanship in the original brazing.
Number Three,	1891	5½ ins. diameter copper steam pipe burst at the brazed joint of the bend near throttle valve. The brazing was thought to be defective, and the accident was attributed to the presence of water in the pipe.
Greencastle, .	1891	Steam pipe broke at the flange on throttle valve. An expansion joint was fitted, but it was not so arranged as to take the strain off the flange.
Rohilla, . . .	1891	Copper pipe 14 ins. in diameter, failed at the seam, which was rivetted and brazed. Accident was attributed to the presence of water in the pipe.

LIST OF VESSELS IN WHICH INQUIRIES, &c. (*continued*).

Name of Vessel.	Date of Casualty.	Casualty, Cause, &c.
City of Lincoln,	1891	Copper pipe 6½ ins. in diameter, cracked through the solid copper at the edge of brazed seam. Accident was attributed to the presence of water in the pipe and to the existence of old flaws.
Shannon, . .	1892	Branch steam pipe of copper 8 ins. in diameter burst. Accident was attributed to the impact of water in the pipe, set in motion by the admission of steam from an auxiliary boiler.
Vulcan, . . .	1892	Main steam pipe 6 ins. in diameter, failed at brazed seam, after five years' use. Probably due to the development of a latent defect, and possibly through want of sufficient provision for expansion.
Grimsby, . .	1892	Main steam pipe $9\frac{11}{16}$ ins. in diameter, burst at a part adjacent to the brazed seam. Casualty attributed to water in the pipe set in motion when the stop valve was opened.
Astrion, . . .	1892	Copper T piece, exploded at the junction of two 6-in. pipes with one of 9 ins. Failure was attributed to the movement of the boilers and to the expansion joint having become set fast.
Viola, . . .	1892	Stop valve box of cast iron burst. Accident was attributed to the accumulation of water in the steam pipe, the draining arrangements having been allowed to get out of order.
Othello, . . .	1893	Small steam pipe 1¼ ins. in diameter, burst by tearing away from the flange. Attributed to vibration of engines.
Astrakhan, . .	1893	Winch steam pipe broke, due to water in the pipe being set in motion when steam was turned on.

Repair of Copper Pipes.—The most common form of repair is by the application of a patch over a small hole caused by corrosion, or over a rent developed along the length of a pipe.

The metal is carefully cleaned with a file, emery paper, sand, and acid, and is brightened around the weak spot. The patch to be applied is cut out of sheet copper, of thickness not greater than that of the material of the pipe, and is shaped to overlap the rent; it is bound in its place by wire. If the patch is made from too thick a material it will obstruct the passage of heat to the spelter and the surrounding material may be burnt. A clear bright coke fire is made on the smith's forge and the pipe is placed in position; the spelter is mixed with borax and is applied from the inside of the pipe, being caused to flow between the patch and pipe, and is prevented from running right through, by skilled manipulation with an iron poker.

An important point in connection with brazing is the application of the loam, which is applied on the pipe to direct the heat to the required spot and to protect the neighbouring flange or metal. If a pipe leak through the fillet on the neck of a flange, a stout piece of copper wire is tightly stretched around the bead, and spelter is run over it. Loam must be applied to protect the under surface of the flange, and is built up to form a wall to enclose the melted spelter. The heat is transmitted through the inside of the pipe, which is hung vertically over the fire so that the under side of the flange is as close as possible. The top of the pipe is usually closed with an iron plate, to prevent a current of cold air passing through. It will frequently happen that the metal of the pipe has been eaten away in the flange; in such a case the flange must be cut off and rebrazed on the shortened pipe. It will be necessary to insert, at the joint, a loose distance flange of the requisite thickness, to make up for the shortened length of the pipe.

Joints.—The remaking of defective joints forms a considerable portion of the total work of repair. In warships, after firing practice, the engineer is sure to find a number of puddles on the plates, caused by the drip from a leaky joint overhead. Leaky joints should be re-made as soon as possible, as they cause the parts in their vicinity to be rapidly corroded. The material most used for joints of steam pipe flanges is red lead, mixed with white lead and oil into a fairly thick paste. The paste is spread uniformly over the joint, and a length of asbestos twine is then laid inside the bolt circle. For pressures of 155 lbs. per sq. in. the paste is strengthened and improved by mixing with it a quantity of shredded asbestos, which may be obtained by unravelling gland packing. As an alternative a wire gauze joint is cut and covered with thin red lead. Asbestos sheeting is also used, but is rather permeable, and if water be present in the pipe an asbestos joint will probably leak. To prevent this both sides of the asbestos should be painted with red lead before it is inserted in the joint.

The joints of steel steam pipes for high-pressure steam have been previously mentioned (see p. 152).

India-rubber insertion is used for cold water joints only, such as those on bilge and circulating pumps.

Asbestos sheeting or rows of asbestos tape are used for joints which have frequently to be broken, such as those of cylinder manholes and evaporator covers, to save the expenditure of red lead. When wire gauze or sheeting is used for joints it sometimes happens that the workman forgets to cut out the central part, and hence the passage of the steam or water is blocked. No joints on steam pipes will give satisfaction unless proper provision is made for expansion and contraction. The nuts of tie bolts securing expansion glands should be protected against unauthorised alteration; a case has occurred in which the whole line of joints on a steam pipe were broken through, these nuts being ignorantly screwed up hard when the pipes were hot and expanded. Joint flanges must be sufficiently thick, and the pitch of the bolts must be small enough, to prevent the flanges springing when the joint is screwed up, or when the pressure is applied. Flanges which were originally too thin are often found "cupped" when the joint is parted; the face of the cupped flange must then be levelled, thereby further weakening it.

The faces of two flanges to be connected must, of course, lie perfectly parallel, and should on no account be pulled fair by the bolts. The flanges should be of sufficient width, and should be so placed that a spanner can be properly fitted on all the nuts, to enable them to be properly tightened up. A joint often gives trouble because the flanges are so near a bulkhead that some of the nuts are difficult of access. In such cases, the joint can be more easily pulled up tight if the nuts are made of double the ordinary depth, with two hexagons machined on them one above the other, the points of one hexagon halving the faces of the other. In the case of awkward single bolts, a nut of double the usual depth may enable the spanner to clear the adjacent nuts.

To Refill a Bearing with White Metal.—Ascertain that the brass fits its seating, it may have been closed in by overheating; next make centre pop marks on the two flat faces of the brass at opposite ends of a diameter, and fit a trammel to the measurement, corrected if found necessary. During the "filling," a brass may alter in diameter and the trammel is necessary for re-adjustment later. Make chisel marks on the ends of the brass to mark the position of the brass dividing strips between the areas of white metal. The white metal lying above these strips after refilling is removed in a planing machine or by chipping. To remove the old metal, the brass is placed over a wood fire laid on an iron floor-plate, and the metal is run out; this process also removes any grease. When the brass is cool it is placed in a bath of sulphuric acid for fifteen to thirty minutes; it is afterwards well scoured with sand or ashes. The brass is then sponged with spirits of salt, and is placed on the forge for tinning. The bearing being uniformly heated, the tinning is effected by rubbing sticks of tin over the heated surface; sal ammoniac is freely thrown on the melting tin, and the latter is spread uniformly over the surface by a piece of clean oakum. The operation of tinning a brass of about 20 inches diameter should occupy about two hours, as it is important that a well-tinned surface should be secured. The hot bearing is now placed in sand, and the mandril, after being whitewashed, is then supported in the bearing, in the proper position to obtain the requisite thickness of white metal by resting it on small distance pieces of the same material. The ends of the bearing are closed by thin flat plates embedded in the sand; the melted white metal is then poured in the annular space from a suitable iron-melting ladle or pot. At this stage the brass should still be too hot to touch. The white metal should be poured in as quickly as possible, to ensure that the whole bulk is liquid at the same time; the proper temperature for pouring Babbett's metal is 580° to 600° F. When the metal is cooling, hot iron rods should be applied to the top surface to ensure that the white metal cools from the bottom upwards, and to prevent the metal becoming porous. In filling small bearings the mandril can be dispensed with and the brass can be filled up solid; later, the superfluous metal can be removed by a red-hot iron bar of a diameter rather smaller than the journal. The use of red-hot iron bars is also applicable to remove superfluous metal in large bearings. After the white metal has set and the bearing is cool, it is opened out to the proper dimension, as shown necessary by the trammel, by hammering the white metal surface. The rough surface must be turned up, or filed if no lathe is available, and scraped until the bearing receives a proper marking from the journal.

The operation of tinning a large iron or steel thrust collar is more troublesome than in the case of a brass; about six hours is required for the two sides, and the tin must be well rubbed in with flat-ended iron rods. In tinning the reverse side, the heat must be regulated so that the tin on the side towards the fire is not run off. The two sides of the collar are filled with white metal in one operation. To do this, the collar is placed flat over a large cast-iron block about 4 inches in thickness, and is supported at about 1 to $\frac{3}{4}$ of an inch above the block by suitable packing. "Irons" of $\frac{1}{16}$-inch plate are cut to confine the white metal on the inside and outside circumference of the rubbing surfaces. The ahead and astern white metal surfaces are connected by a proper number of holes bored through the steel casting, and also by large passage-ways arranged by bending in the inner or smaller "iron." After the white metal has been poured, the upper surface is kept molten by red-hot iron rods, and a little more white metal is poured on from time to time as the surface sinks. In order to obtain a suitable close surface, it should be arranged that from $\frac{1}{2}$ to $\frac{3}{4}$ of an inch is turned off the thickness of both faces in the lathe.* The composition of the white metal used in bearings varies somewhat; the following mixture has given very good results in engine bearings:—Copper, 1·8 per cent.; tin, 89·3 per cent.; antimony, 8·9 per cent.

Casting.—Brass castings can be made on board ship. The sand mould is made, as in the shops, in suitable boxes. To melt the brass the smith's forge is employed. The crucible containing the brass is surrounded by a coke fire, built up and enclosed by a temporary arrangement of firebricks. No special difficulties are experienced, by a capable workman, other than those common to shop practice. Iron castings have also been made; an iron drum was used as a cupola, air being supplied by a temporary trunk led from one of the ship's fans.

DRY DOCKING.

Steel ships which are not sheathed with wood require to be docked once in six months, in order that the skin plating may be cleaned and recoated with composition. Before entering dry dock the chief engineer is expected to bring the ship upright by pumping up or running down the water in some of the boilers, by flooding a wing compartment, or occasionally by training the barbette guns. A special plummet is hung in a particular place for this purpose. Whilst in dock the trim is preserved, and no material changes are made in the disposition of the heavy weights carried. The coal used in dock must be taken equally from both sides, and if boilers are run down for cleaning they must be treated in pairs, one on each side of the ship.

As the water is pumped out of the dock the deck hands scrape and scrub down the side, from floating stages; later, the men of the constructor's department apply the composition, from stages slung around the ship's sides and erected from the dock floor.

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* In the coppersmith's shop, the thrust collar is placed in a vertical plane, secured in a proper sheet-steel casing, which latter can be used for the whole set of collars.

On entering dock the engineer stops the circulating engines in good time and diverts the exhaust steam from the auxiliary engines to the atmosphere, since after the water is pumped out of the dock there will be no circulating water for the condensers. A hose is then rigged from a shore hydrant to supply fresh feed-water to the boilers in use for auxiliary machinery. In H.M. dockyards a demand note for the fresh water required must be sent in previously to entering dock.

The various groups of flooding valves, for the magazines, are connected up by hose to a salt-water hydrant from the shore, the hose pipes are screwed on to the deck attachments of the special pipes communicating with the flooding pipes.

Hose connections are also made from the shore hydrant to the fire main, for use in case of a fire occurring on board.

Under-water Fittings.—The department is employed in refitting the sea inlet and outlet Kingston valves, and the various zinc protectors; also in examining and testing the propellers, stern gland packing, and outer shafting whilst the ship is in dry dock.

LIST OF SEA VALVES.

Inlet and outlet valves for main condensers.
" " auxiliary condensers.
" " fire and bilge engines.
" " hand pumps throughout ship.
" " evaporators and distillers.
Sea-suction valves and cocks of feed pumps.
Blow-out valves and cocks for boilers.
Inlet for circulating water to air compressors.
Outlets for submerged torpedo tubes.

Refitting Valves.—The refit of the above Kingston valves and sea cocks comprises the following operations:—Remove the outside gratings fitted to suction orifices, clean the gratings; scrape and clean the tubes leading through the D.B. or wing spaces; remove the valves, clean them and refit them and their seatings. Valves which are badly pitted should be turned up in the lathe. Any internal pipes suspected of being choked should be removed and cleared if necessary. The zinc protectors fitted to all inlet and outlet tubes are examined, and renewed if necessary. The valves must be examined to make sure that they are properly secured in place and closed, and that the gratings over the inlets are replaced with the nuts secured on the studs by split pins, before the ship is floated. After the valves are replaced, and before the gratings are replaced, the tubes are painted with the composition used for the ship's bottom.* Special plugs, for the more important outlets, are provided. They are carried on long levers, which are hung in brackets on the ship's side by pivots at the middle of the length. The upper end of the lever being forced out from the upper deck, the plug is jammed into the orifice below. These plugs are made water-tight by means of an india-rubber joint, which may be coated with white lead and tallow. Whenever the ship is in dry dock, these plugs are adjusted and examined in place.

Propeller Shafting.—On every occasion of the ship going into dock the outer shafting should be carefully examined; and, if not covered with brass throughout, the steel parts should be thoroughly scraped, cleaned, and painted with red lead, all signs of rust being first removed. If pitting is observed, protective zinc slabs may be fitted on the shaft. There are zinc plates fitted on the stern tube and on the A frame which must be examined. The wear in the bearings of the A frame, and in the end of the stern tube, is noted by means of wooden wedges about ½ inch wide, which are driven in; when withdrawn, the maximum thickness of the part which entered is measured. At the same time, the amount of white metal, or lignum vitæ strips, to be worn down before the shaft touches the liners should be measured in the above bearings; if necessary, these bearings should be lined up. Withdrawable liners to facilitate this renewal are now usually fitted, otherwise the shafting must be withdrawn. The propeller nut should be taken off to see if water has had access to the thread, and, after the examination, this nut must be carefully jointed; in any case, the nut should be hammered up hard, whether taken off or not, and the keeps should be refitted as requisite; the cover plates should be removed, and the bolts securing the blades should be examined. The surfaces of the blades should be cleaned and smoothed, any pitting which may have occurred, generally at the back of the leading edge, being noted.†

In some ships sheathed with copper, it has been found that the bronze propeller blades have suffered from extensive corrosion down the back of the leading edges and all over the outer third of the back surface of the blades. The Admiralty direct that the corroded surface is to be smoothed as far as practicable, without unduly reducing the thickness, the edges are to be trimmed, and the pits remaining are to be filled with gold size stopping, and the whole surfaces are to be afterwards smoothed. No outer bottom composition whatever is to be applied. If gold size stopping is not available, a wash of Portland cement, covered afterwards with a coat of red-lead paint, will give good protection.

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* See *Lewis' Service Chemistry*, p. 444, for anti-fouling composition.

† The holes drilled in propeller blades for the attachment of the lifting shackles should be fitted with tight-fitting wooden plugs. In some cases the wash of air and water through these holes has eroded grooves on the back surface of the blades in the wake of the holes.

In the case of a general refit, the bosses should be removed to examine the shaft cone; this is more urgently needed when no gland is fitted at the forward end of the boss, because, in such cases, rapid deterioration of the shaft at the fore part of the boss has been noted. An indication of such corrosion may be given by rust marks on the fore face of the boss. All small screws and bolts should be sounded and otherwise examined, as cases have recently occurred where the whole of these fittings required renewal. If made of good rolled naval brass, they are reliable and lasting. See that the key securing the boss fits tightly.

The friction test of the shafting is made thus:—The coupling bolts of the inside after coupling are withdrawn, and, if desirable, the packing is taken out of the stern gland. One end of a spring balance is attached to a certain blade at a known radius, where a hole is generally provided for an eye bolt. The blade selected is placed in a favourable position, and a tackle is attached to the other end of the spring balance; the shafting is then pulled round by means of this attachment, and the lowest reading on the spring balance is noted. This will be obtained when the pull is at right angles to the blade. The record made includes particulars of the amount of the weight or pull, the radius of application, and the condition of the stern gland.

Pitch of Propeller.—To measure the pitch of a blade fitted in place on a shaft, fit a long batten with a cross-piece firmly attached to one end, and shaped to the curvature of any suitable turned flange on the boss or nut, in such a manner that the batten can swing around the axis of the shaft as a centre, and in a plane perpendicular to the axis of the shaft. Select a point, P (Fig. 41), on the batten, distant *r* from the centre, O. Mark two points, A and B, on the blade at the radius, *r*. Measure the distance A B, which should not be large, and the distances P A, P^1 B; the two latter must be perpendicular to the batten.

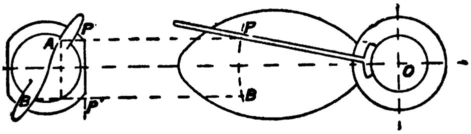

Fig. 41.—Measuring the Pitch of a Propeller.

Let $AB = C, \quad P^1B - PA = a, \quad PP^1 = b.$

Then $C^2 - a^2 = b^2; \quad \text{and } b : 2\pi r :: a : \text{pitch}.$

As blades often have a variable pitch, these measurements should be made at as many points as thought necessary.

Fig. 42 shows a more accurate arrangement used in the dockyard to ascertain the pitch of a propeller. The apparatus consists of a gunmetal ring or base plate mounted on a wood framing, which is slipped over the propeller nut and secured flat against the turned face of the boss by means of the studs fitted for securing the bonnet of the nut. The circumference of this base ring is fixed concentric with the shaft, with its face at right angles to the axis of the shaft. Turning on the base ring, in a parallel plane, is a second gunmetal ring, with its circumference graduated in degrees. A pointer on the base ring marks the angle through which the movable ring is turned. The second ring carries a graduated radial arm, which can thus be revolved in a plane at right angles to the axis of the shaft. A graduated pointer is carried on the radial arm, as shown, and can be clamped at any desired radius. This pointer can be

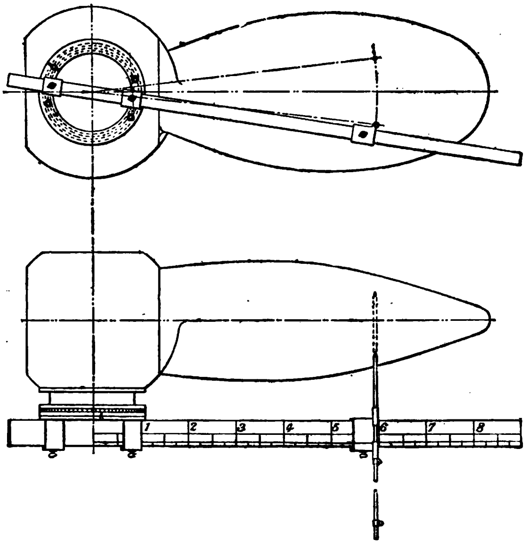

Fig. 42.

moved, in a direction parallel to the axis of the shaft, to touch the surface of the blade, and the difference of two readings on the pointer for a known arc of turning of the second ring gives a measure of the pitch at a certain radius. The graduations of the second disc can conveniently show arcs of 10° around its circumference; if the difference of the readings of the pointer when touching the surface of the blade at the two ends of an arc of 10° be p inches, then the pitch of the blade at this radius will be $\frac{p}{12} \times \frac{360}{10} = 3p$ feet.

LIST OF MORE IMPORTANT SPARE GEAR CARRIED IN H.M. SHIPS.*

(*a*) For the Main Engines:—

Air pump connecting-rods or links,	1 set
Air pump rod complete,	1 in no.
Bolts and nuts complete for one main shaft coupling,	½ set.
Bolts and nuts, turned and fitted for engines, assorted,	80.
Bolts for junk rings,	1 set.
Brasses for link motion,	1 of each size.
Connecting-rod bolts and brasses complete for each end,	2 sets of brasses for one rod, and 1 set of bolts.
Cylinder valve faces and screws complete, or piston valve liners,	1 of each size.
Eccentric-rod and strap complete, of each kind,	1 in no.
Filtering material and frames for grease extractors,	3 sets.
Lignum vitæ strips and facings, for all parts so fitted,	1 set.
Packing, metallic,	Sufficient for two piston-rods and one set of each other size.
Packing rings complete for flat slide valves,	1 set for each size.
Packing rings complete for piston,	1 set for each cylinder.
Packing rings for air-pump pistons,	1 for each fitted.
Piston complete for low-pressure cylinder,	1 in no.
Piston rings for piston valves,	1 set for each valve.
Piston-rod crosshead slipper,	1 in no. for each kind.
Piston-rods of each size, complete,	1 in no.
Propeller blade, right and left handed, complete with bolts,	1 of each hand.
Slide rod of each size,	1 in no.
Springs for each piston for one set of engines,	½ set.
Thrust collars for one set of engines,	1 set.
Valves I.R. for each fitted,	2 in no.
Valves, metallic,	½ set.
White metal bearings, mandrils for,	1 set.
Zinc fittings for condensers,	3 sets.

(*b*) For the Auxiliary Engines:—The establishment of spare gear is equally extensive.

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* This list is not given as exact for any particular ship.

When spare gear is provided suitable for a number of different positions, the final fitting is generally left till the occasion arises, in order to allow for small variations caused by wear; and the following or similar differences may be found:—

Piston-rods.— Spare rod too large, necessitating new neck bushes and packing, owing to working rod having been trued or skimmed up. Slipper to be adjusted to guide face. Piston cone to be fitted.

Crank shaft.—Coupling bolt holes to be broached out, keyways for eccentrics or turning wheel to be cut. Brasses may be too small for the new journals.

Crank-pin brasses.—Size or pitch of bolt holes to be adjusted. White metal of bearing to be turned out or eased at the horns owing to the allowance left for the wear of journal; oilways to be cut.

Piston spring ring may be either too narrow or too wide, involving work on the junk ring or on the spring ring itself.

CHAPTER IX.

PRESERVATION AND REPAIRS OF BOILERS.

Maintenance — Fresh Feed-water. — In H. M. vessels every endeavour is made to keep the feed-water fresh and free from salt or oil. The water required to make good that lost by leakage is supplied by a powerful distilling plant (see *Auxiliary Machinery*), and sea water is no longer supplied to the boilers under normal conditions of working. A sea suction pipe is, however, still fitted to the auxiliary feed pumps, for use in case of emergency; this suction pipe is fitted with an additional valve, to lessen, as far as possible, the chance of sea water leaking through when the pumps are in use on the reserve or feed tanks.

Filtration.—The condensed steam from the hot wells is filtered by passing through special filter tanks containing clean cinders or coke, or diaphragms over which a covering of Turkey towelling, sacking, or other suitable material is fixed. The oil and dirt are retained in the filter tanks, and the interior fittings must be cleaned or renewed at regular intervals. The filter tanks are often placed above the level of the feed tanks, and a special hot-well pump is then fitted to draw the water from the air pump hot well and lift it to the filter tanks, hence the duty of the air pump is not increased. Although the use of feed-water filters is beneficial, yet every effort must be made to reduce the quantity of oil introduced into the cylinders. In recent practice the greater part is introduced by the piston and slide rods.

Changing the Water.—The water in the boilers should not be changed, unless this course is necessary for cleaning purposes or because the density is too high, since the air admitted on refilling is prejudicial and causes corrosion.

Acidity.—Any tallow and vegetable oils which may be carried into a boiler become decomposed and form fatty acids, but the water in the boilers may be kept neutral by the addition of soda to the feed-water. The soda is dissolved in hot water and added to the feed-water through the soda cocks on the condensers. A very small quantity suffices under the conditions of recent practice. The water is tested from time to time by litmus paper.[*] A number of small tins, painted with numerals and fitting in a tray, is convenient for this purpose. The water being drawn from each boiler into the corresponding tin, through the hydrometer cock, the tray can then be carried aylight for the test.

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[*] See footnote, p. 94.

Preservation of Boilers not in Use.—If the boilers of a ship in commission are likely to be out of use for several consecutive days, the practice is to pump them full up with fresh feed-water. In order to make sure that the boiler is quite full a small pressure of 5 to 10 lbs. per square inch is maintained by a feed pump, which is started, when necessary, for this purpose. To provide a larger reserve of fresh water, a ship will start from a port—where good water is obtainable—with such boilers as are not in use filled to W.W. (see p. 175), and a small pressure should be maintained in them.

When boilers are to be out of use for some time, the methods (see *Steam Manual*, Art. 281) for their preservation were formerly as follows:—

The boiler may be emptied and thoroughly dried out by the use of airing stoves. All doors are then replaced except a lower manhole door, through which perforated trays, or small bogies, containing burning charcoal, are inserted. The boiler is then hermetically closed, and all the oxygen contained in it is consumed by the charcoal.

The boiler may be completely filled with fresh water and soda, the proportion should be 1 lb. of soda crystals, or ½ lb. of soda ash to 100 lbs. of water. A boiler so treated must be thoroughly washed out before use, otherwise priming will result.

When a ship is passed into the Reserve, the boilers are emptied and all the doors are taken off; the boiler is thoroughly dried out, and is kept dry by means of fires, which are made in bogies placed in the furnaces. After the boilers have been thoroughly cleaned, trays containing 2 or 3 cwts. of quicklime are placed inside the shell; bogies containing coke are then lit in the furnaces, and a lighted coke bogey is placed in the boiler, to produce a thoroughly dry atmosphere; and then the boiler doors are replaced and the boiler is hermetically closed.

The above methods were superseded by the following method, which forms part of a circular letter issued by the Admiralty on 11th December, 1903:—

"My Lords Commissioners of the Admiralty having had before them the results of experiments respecting the corrosion and pitting of boiler tubes, and, as experience has shown that in all cases the best method of preservation is to keep boilers, when not in use, quite full of fresh water, have decided that this course is to be followed in future, whether the ships be in Commission or in Reserve. The absolute necessity of this course cannot be too fully recognised by Officers Commanding and Engineer Officers.

"With a view of removing any scale or dirt that may be accumulating or forming in the interiors of the tubes of boilers of the water-tube type, the boilers in all ships so fitted, whether in Commission or Reserve, are to be steamed at a high rate of evaporation for not less than four hours at least every four months, after which they are to be thoroughly cleaned, closed up, and filled with fresh water as before."

Cleaning.—For the ordinary work of cleaning the tubes and firegrates of a boiler after steaming, see the remarks in the chapter on "Shutting off Steam."

The interior of a boiler, fed solely with fresh water, should be examined and cleaned at intervals of not more than thirty steaming days. The water from the boiler, if fresh and clean, is run down to the reserve tanks through a portable canvas hose attached to the running-down valve on the boiler. It should be remarked that if the water is strongly alkaline, owing to a large quantity of soda in solution, leather hoses, if used, will be quickly dissolved. The latest practice in the Royal Navy has been to dispense with the bottom blow-out valve and levelling pipes, and to substitute a running-down valve with an attachment for a hose. The risk of salting a boiler through carelessness is thus diminished and the bottom blow-out valve is not now required for brining. The boiler is not run down until twenty-four hours after fires are out, in order to allow it to cool gradually. When the boiler is empty all the manhole doors are taken off, and the boiler is thoroughly aired before anyone is allowed to enter. Accumulations of hydrogen have caused explosions when this precaution had been neglected. The stop valves must be closed and securely lashed, or the wheels removed from the spindles, and the feed valves secured to prevent any accidental communication with the steam pipes or feed pumps. The bottom of the boiler must be thoroughly dried up, and kept so while open to the atmosphere.

The top manhole door should be taken off before the boiler is run down, and the various other doors as soon as the water-level is below them. It is important to do this, in order that the boiler may be aired, and the men at work scraping off the deposit before it has time to dry, since when dry the deposit is more difficult to remove.

The boiler will generally require most attention on the under side of the furnaces, and around the water line, where a soft oily deposit is to be found, which may extend to the tops of the furnaces. The confined spaces are cleaned and scraped by means of long scrapers; small men must be selected for the spaces accessible through the manholes on the front plate. If a ring of scale has been formed around the tube ends where they enter the tube plates, it may be necessary to draw a certain number of tubes to provide access to the remainder. The ends of the tubes which are drawn should be annealed before replacement (see *Steam Manual*, Art. 217). The zincs must be thoroughly examined and the thin plates renewed, for which purpose the hangers should be withdrawn in order that a bright metallic contact may be ensured. The metallic contact must be renewed at least once in six months. Those zincs which are not withdrawn are examined to make sure that they are firmly secured. The zincs in the steam space are less effective and have a longer life than those actually immersed. The stays must be callipered, and the surfaces of the shells around the water line, crowns of furnaces, and combustion chambers must be closely examined to detect possible corrosion. The internal steam pipe and gauge glass connections are examined and cleared. The internal steam pipes are sometimes found collapsed, and must then be renewed. The glands of the feed valves and the joints of the covers must be re-packed, or re-made, as necessary, and the hydrometer cocks should be refitted. Valves which are rarely used—and others from some peculiarity of their position—are liable to collect deposits of dirt, and should receive special attention.

After the interior has been thoroughly cleaned, and well washed out by a jet of water supplied under pressure, the zincs and other fittings are replaced, and the surface of the shell plates at the water line is coated with a wash of cement, over a width of about 18 ins.

The boiler should then be examined by an officer, and, if found satisfactory, the lower manhole doors should be replaced. After the boiler has been pumped up, the surface of the water can be cleaned and the top manhole door replaced.

All manhole doors are made by asbestos rings, which should be of accurate shape and thickness, otherwise a leaky joint will result and will involve the inconvenience of emptying the boiler to rectify it.

The time required to clean out a boiler, which has been supplied with fresh water only, is from two to three days; if the zinc plates require much attention, this time will be exceeded. Article 227 of the *Steam Manual* directs that if the periodical cleaning is not carried out, the reason is to be inserted in the engine-room register.

Salt Water Make Up.—If the lost feed-water is made up from the sea, the boiler water will acquire a certain density, and scale will be deposited. The amount of hard scale depends mainly on the amount of salt water supplied—that is, on the density at which the boilers are worked—being less the higher the density. It is found that boilers, supplied with salt water make up, require to be opened up and cleaned after about 25 days' continuous work. The work of cleaning is laborious, as there will be a quantity of scale on the tubes and other internal surfaces which must be removed by concussion and scraping. All scale should be removed from the heating surfaces.

Pitting.—On all occasions of the above monthly examinations the surface of the plates should be thoroughly examined to detect any signs of corrosion. If pitting is discovered, the plates should be thoroughly scraped until the metal is reached, and if the surface affected is not part of the heating surface it should be washed over with thin Portland cement. Additional zinc slabs fitted near the parts affected will probably be of advantage; in arranging them they should be placed so that, if they break up, the *débris* will not fall and remain on a heating surface.

The following article on pitting is quoted from *Engineering*:—"In an article recently published, M. Olroy, a French engineer, gives the result of his investigation into the pitting of boilers. Pitting is particularly likely to occur if a water very free from lime is used in a clean boiler. The pits take the form of conical, or more frequently spherical depressions, which are filled with a yellowish-brown deposit consisting mainly of iron oxide. The volume of the powder is greater than that of the metal oxidised, so that a blister is formed above the pit, which has a skin as thin as an egg shell. This skin contains usually both iron oxide and lime salts, and differs greatly in toughness. In many cases it is so friable that it breaks with the least shock, falling to powder, whilst in other cases the blister detaches itself from the plate as a whole. An analysis of the powder in the pits showed it to consist of 86·26 per cent. of peroxide of iron, 6·29 per cent. of grease and other organic matter, and 4·25 per cent. of lime salts, the remainder being water, silica, aluminium, &c. The skin over the pits was found to contain 38 parts of calcium carbonate, 12·8 parts of calcium sulphate, and 32·2 parts of iron oxide, with about 8 per cent. each of magnesium carbonate and insoluble matter. Feed heaters often suffer badly from pitting, particularly near the cold water inlet, and in boilers the parts most likely to be attacked are those where the circulation is bad, especially if such portions are also near the feed inlet. In locomotives, the bottom of the barrel is most frequently attacked, and the largest ring. The steam spaces are generally free from pitting, unless the boiler is frequently kept standing with water in it. As the water evaporates, pitting is then likely to occur along the region of the water line, a part which, in a working boiler, is generally free from attack. This is especially the case if longitudinal joints of the boiler are liable to be exposed by the evaporation of the water, and to form a ledge on which moisture can rest. When a boiler forms one of a battery, and is kept standing for a long interval, the top of the boiler is liable to pitting. Steam finds its way into it, and condenses on the roof, causing bad pitting there. Perfectly pure water containing no air does no harm, and steam alone will not cause pitting, unless it gets a supply of air. The Loch Katrine water of Glasgow, which causes pitting on clean boilers, contains much gas. MM.

Scheurer-Kestner and Meunier-Dolfus inclosed a polished iron bar in a natural water containing much oxygen, and no lime salts. The bar gradually rusted, but the corrosion ceased when the oxygen was used up. The bar was then removed, re-polished, and put back, after which it remained perfectly bright. Repeating the experiment with water containing lime, the rusting was much less complete, the lime salts forming a protective layer on the iron, but on polishing this off corrosion recommenced. In distilled water the bar remained quite bright. The corrosion is much more rapid if the water contains carbonic acid gas as well as oxygen. In this case a voltaic action takes place. The rust first formed is electro-positive to the iron, which then dissolves away, decomposing the water. It is for this reason that, in cases of pitting, it is essential that all traces of the iron peroxide should be cleaned from the metal, or the rusting will continue."

The following extracts are taken from a paper read by Mr. Couper before the Institution of Shipbuilders and Engineers of Scotland in 1896, and the subsequent discussion on "Internal Corrosion in Steam Boilers":—

Corrosion is caused mainly by (1) air and carbonic acid gas dissolved in the feed-water, the action of which is very manifest when the feed-water is introduced at a part of the boiler where the circulation is bad (see p. 170). (2) By fatty acids formed by the action of an alkali on tallow or vegetable oils. To minimise the first action, the orifices of the feed pipes should be near the water level, so that the air, when expelled by heat, may at once pass away freely with the steam. Rough corroded surfaces are most favourable to the liberation of gases in solution (as may be seen when a soda-water bottle is opened), and local corrosion, once initiated, is accelerated by that property.

Mr. Stromeyer pointed out that the air was not necessarily expelled from feed-water heated under pressure in feed heaters, whilst at the same temperature it would be liberated from a free surface; and, further, that perfectly clear water holds more air in solution than water which contains floating particles of mud. Mr. Stromeyer further stated that corrosion in the steam space of a boiler could be reduced by coating the cleaned surface with zinc white paint, and by adding some form of zinc salt to the boiler water.

Mr. James Weir said that the ordinary scale formed by the union of iron and oxygen forms a perfect protection to plates, but the carbonic acid gas in solution with the feed-water removes this scale and forms ferrous carbonate (Fe_2CO_3). The plate is thus left exposed to the action of oxygen, and more oxide is formed and is in its turn removed.

Slow-moving feed pumps appear to draw less air with the feed-water than fast-moving pumps. Excessive capacity in the feed pumps leads to a larger supply of air to the boilers. Probably not the least benefit of automatic feed pumps is the decreased supply of air experienced. If duplicate pumps are fitted to a group of boilers, each capable of supplying all the boilers, only one should be used for general steaming, unless automatic regulating gear is fitted to both.

As regards the action of fatty acids, Mr. Couper said:—All boilers should be thoroughly washed out and cleaned with soda ash (Na_2CO_3) before steam is raised for the first time. After a preliminary steaming, scumming should be resorted to, and then all the remaining water should be blown out, and the boilers should be opened up and cleaned out. The blow-off cock should be capable of completely draining the boiler. When the boiler is refilled, soda should be added to the water. A red or black slime is often found in new boilers, being formed by the mill scale detached from the plates—red, if the plates left the mills at a low temperature; black, if the plates were annealed. This coloured slime should not be taken as evidence of corrosion, and should not reappear after being properly cleared out.

Tests.—In addition to the monthly examination of the boilers, the following tests are ordered to be made in H.M. service :—

The drill test (see Art. 304, *Steam Manual*) is to take place at intervals of not less than eighteen months, or more than two years, whilst the ship is in commission, one boiler in four being tested. In H.M. service the procedure is as follows :—The chief engineer of the ship reports on form S. 356 that the drill test is due, and quotes the date of the last drill test. The commander-in-chief then orders a senior chief engineer to communicate with the commanding officer and the chief engineer in charge, with the view of arranging for the necessary test and examination. The parts of the boiler to be drilled are given later; the following report is made :—A description of the appearance, thickness, and nature of the deposits on various surfaces is to be given; the condition and estimated durability of the zinc slabs is to be reported. Should there be any defects, or symptoms of corrosion, the report is to state what they are and what remedies have been applied. The original and present sizes of stays and the apparent wear is to be given.

The drill test is carried out by drilling holes through the plates at the places given later. After the holes are drilled the burrs must be carefully removed from both sides of the plate and the thickness of the various plates measured and compared with the original thickness. These holes are afterwards tapped, and screwed plugs are inserted, which are securely rivetted over so that no leakage shall occur.

If unexpected wear be discovered on drilling, the plate should, if accessible, be examined on both sides in the vicinity of the thin part, and other holes should be drilled in suitable positions in order to ascertain if the wear is local or general. The formulæ in general use (Admiralty, Board of Trade, or Lloyd's) can be advantageously applied to the results of the drill test to aid in deciding whether the working pressure must be reduced and to what extent, and also to decide what repairs are necessary.

In "tank" boilers* the parts of the boiler to be drilled are:—

Shell, { Steam space—Top, sides, back, and front.
At water level—Sides, back, front.
Below water level—Sides, bottom, back, front.

Tube plates—Back and front.
Furnaces—Crown, sides, bottom, back.
Combustion chambers—Top, back, sides, bottom, saddle plate.
Uptake—Back, front, sides, top.
Smokebox—Bottom, sides.

The report includes particulars of the original thickness, the minimum thickness at the last drill test, the thicknesses found at the present test and the amount of the apparent wear from the original thickness, at each of the places detailed. The condition and wear of the tubes should be specially noted.

A sketch is to accompany the report showing the positions of the holes drilled at each test.

The water-pressure test (see Art. 292, *S.M.*) is to be made after two years' service, and then at intervals of six months. It is intended to supplement and not to supersede the drill test. The following particulars of the test are the most important of those to be reported:—The greatest pressure applied; the load on the safety valves when first fitted, and at the date of the test. The date of construction and makers of the boilers; the date of the last repair, and for what duration of service. The effect of the test on the plates of furnaces, combustion chambers, shells, and on the tube plates and stays of combustion chambers, furnaces, and shells. The estimated durability with such repairs as can be made on the station.

The proper form for the report is S. 355.

The points to be observed to carry out the water test of "tank" boilers are as follows:—

1. The pressure to which the boiler is subjected when new is 90 lbs. above the working pressure; unless the latter is less than 90 lbs. per sq. in., in which case the test pressure is double the working pressure.

2. To get the boiler ready, withdraw the springs from the safety valves, substitute long sleeve washers, and screw down the safety valves. Shut all the stop valves tightly, so that they shall not leak under the pressure. Shut off the feed valve not in use for the test. Shut off all gauge glasses, so that they shall not be damaged. Shut off any pressure gauge which will not indicate up to the test pressure. Pump the boiler up, and when water is discharged through the air cock shut it off.

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* For tests of water-tube boilers see the chapter under the heading Machinery of T.B. Destroyers.

The extension-compression gauges supplied must be fitted in the furnaces and combustion chamber to register the change of shape under the pressure; one should be placed horizontally, and one vertically, in each furnace and combustion chamber, to register the change of diameter, or the bulging of the side and top plates respectively. Extension-compression gauges may also be required in other places determined by the arrangement of the stays. As an instance, the stays from the top of the combustion chamber may be attached to an angle bar secured to the circular shell. If the angle bars are not carried round to that part where the shell is at right angles to the top surface of the combustion chamber, then excessive deflections may be registered. To determine if the shell moves down with the top of combustion chamber, place gauges from under the deck to the top of the boiler. These gauges are carefully set at zero just before the pressure is applied. Open all the smokebox doors so that the ends of the tubes can be clearly seen, and provide plenty of lamps for illumination.

The pressure can often be applied by the ordinary feed pumps, if they are in good order and steam is available to drive them. The feed valves on the boilers (not under test), which are supplied by the pumps in use, must be shut tightly. Special liners and smaller plungers for the feed pumps are sometimes available and, if shipped, enable the test pressure to be more easily obtained. If the feed pumps are not available, a large hand pump is used, delivering through a flange, fixed on a feed pipe in such a manner that a group of boilers can be tested, successively, by means of the same connection.

The pressure gauge, recording the pressure attained, should be fixed on the boiler and not on the test pump.

When pumping up it will generally be necessary to tighten up some stop valve or feed valve before leakage is stopped and the test pressure obtained. When the boiler is under pressure, note the position of all extension gauges continuously; if the deflections become abnormal, the pressure should be released to ascertain if there is any permanent set. Increases of pressure should then be gradually applied and removed frequently, to ascertain that the safe limit is not passed. When the pressure is released the extension gauges should all return to zero, showing that no permanent set resulted. The pressure is released by opening the running-down valve; a very small quantity of water will be discharged, since the water itself is almost incompressible; and note here that if continuous pumping is required after the boiler is full the water must be leaking away; if there is no visible leak it is probable that a quantity will be found in the steam pipes connected to the boiler under test, and they must, therefore, be subsequently drained.

The safety valves must be ground in or refitted from time to time, as indicated by the leakage from the waste steam pipe. Before concluding that the safety valves are leaking, ascertain if there are any other connections between the waste steam pipe and other pipes containing steam. In many ships apparent leakage from the safety valves has been traced, through the drain pipes from the safety valve boxes, to the main run of steam drain pipe, owing to leaky valves in the drain pipes.

The waste steam pipe from the safety valves is generally led up close alongside the funnel, and nearly to the same level as the funnel covers; in consequence, a deposit of gritty blacks will generally be found above the valves, and this deposit will frequently choke the drain pipe from the safety valve box. Any water in these boxes will then be evaporated by the heat of the boiler, and produce the appearance of leaky valves. The grits, if ground into the seatings, will make the valves leak. The safety valve boxes in the above case will require frequent clearing. A mushroom cover of thin plate may be placed over the top of the waste steam pipe to keep these blacks out.

The following notation is used in the Royal Navy to denote the condition of boilers:—

W, Water at working height.
W W, Boiler filled completely with water.
S, Boiler in use for main engines making good distance logged.
B, Fires banked, or in use for main engines, not making good distance logged.
A, Fire, alight; boiler in use for auxiliary purposes.
E O, Boiler empty and open; manhole doors off.
E C, Boilers empty and closed.

BOILER REPAIRS.*

(The following notes refer to "tank" boilers only.)

It is of the utmost importance to make frequent, careful, and thorough examinations of the surfaces of all boilers, including the exterior shell surfaces, the heating surfaces, and all parts of the interior; these periodical examinations will lead to the detection of symptoms of decay and of wear; and if, in such cases, the usual rules for the proper working and for the preservation of boilers be carefully followed, decay may in many instances be arrested, and considerable expense in repairs avoided. If these precautions are not taken, defects will probably develop. Defects may also arise through fair wear, and the object of the present chapter is to indicate the nature of some of the defects, and the measures that may be taken to deal with them.

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* This article was kindly contributed by Engineer Commander G. G. Goodwin, R.N.

The exterior surfaces of the shell plates should be kept as dry as possible and, where accessible, well painted. The under parts are especially liable to rusting from the wash of the bilge water; the lower fronts are also liable to wear on account of water running from the ashpits, where water service is used, and these plates especially should be frequently examined, scraped clean, and painted. In small steamboat boilers the wear of the bottom can often be checked by bedding the boiler in a tray of red lead putty.

Leakage at Joints of Mountings.—The upper parts are generally covered with lagging, and where this can be kept dry very little deterioration of the shell plates occurs; but, in parts, the lagging may become and remain damp, owing to leakage from the joints of mountings, overhead steam pipe joints, gauge glasses, &c., and if not promptly attended to the plates underneath will quickly and deeply rust. In such cases, the lagging should be removed from the parts affected, all rust carefully scraped off, the surfaces well painted, and new dry lagging fitted; the leakage causing the wear should be stopped as soon as possible, and should be diverted from the plates in the meantime. If the rusting is deep, the plate should be drilled to ascertain its reduced thickness, and, if necessary, a covering plate or other means fitted to increase its strength.

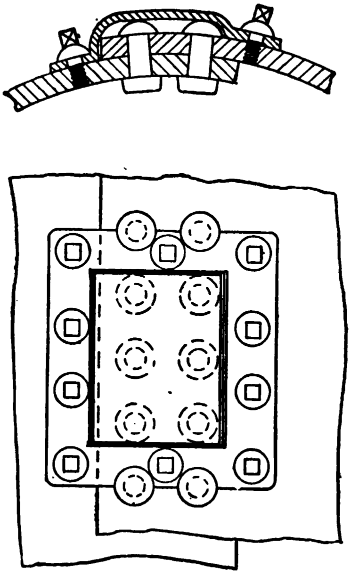

Fig. 43.—Patch over Leaky Rivets.

Leakage at Seams.—In some boilers, especially in long ones, and more particularly where feed-water heaters are not used, leakage often occurs at the circumferential seams at the bottom; if not of great amount, this leakage may be stopped—temporarily, at least—by light caulking, but the caulking should not be carried too far before other measures are taken. Leakage at these and similar joints must not be allowed to continue long, or the constant passage of steam or water at high pressure and velocity over the jointed surfaces will "fret" away the plates at these surfaces, the result being increased leakage, thinning of the plate, and, probably, extensive repairs. In order to stop the leakage and consequent "fretting" action, troublesome joints of this kind are often fitted with patches covering both plates of the joint. These patches are well bedded on to the plates, recesses being formed in them to take the rivet heads; they are jointed on to the plates with red-lead putty, and secured by screwed rivets. The patches may require occasional re-jointing, and the method of securing them renders this an easy matter. Such a patch is shown in Fig. 43.

Heating Surfaces.—The plates, &c., forming the heating surfaces are those in which defects are most likely to develop, the most common being—leakage at joints and stays, bulgings, cracks, and thinned plates.

Leakage may occur at any of the joints, but is most common at three-plate junctions, and at the seams in the furnace throat. The former can generally be remedied by careful caulking, and it may here be stated that in the more recent boilers the number of such junctions has been reduced.

It is more difficult to stop any leakage through the seam at the top of the furnace throat. Such leakage is caused by the resistance offered by the rigidity of the tube plate to the expansion and contraction taking place over the length of the furnace, which resistance produces a strained joint. If the joint is made on the cylindrical part of the furnace, it is, perhaps, better situated for sustaining the strain, but the plan is open to the serious objection that the joint is in the fire—that is, it is in the direct line of passage of the heated gases. If the joint is made by flanging the furnace plate so that it joins the tube plate in the combustion chamber, it is removed from the fiercest action of the heat, but the tendency of the expansion of the furnace is to open the joint. In either case the double thickness of the tube plate and furnace plate at the joint is prejudicial, and the plates are liable to overheating. On the whole, it is considered better to make the joint in the combustion chamber, and this is the method generally adopted in the return tube boilers in the Navy. The plan has a disadvantage, should the necessity arise for renewing the furnace, as, in order to withdraw the old one, so many plates require to be disconnected. The following devices have been resorted to in constructing boilers to reduce the possibility of leakage at the throat seams:—

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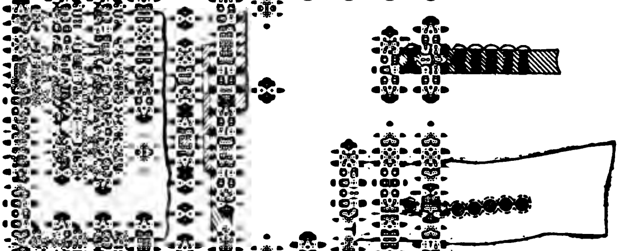

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The heating plates are those most liable to cracks, on account of the severe expansion strains to which they are exposed owing to the unequal action of the heat on the various parts; cracks are most frequently found in the parts which have had considerable work done on them during manufacture before being built into the boiler; in many cases they start from a stay or rivet hole (see Fig. 44).

A short crack in the body of a plate may be dealt with by studding, as shown in Fig. 45; the method adopted is to drill holes all along the crack and fill them with small rivets, knocked down so that the rivet heads overlap.

For longer cracks the defective part should be cut out and a patch fitted. If a crack extends from a rivet hole through the lap of the plate, the cracked plate should be cut away for a distance of several rivet holes from the crack and a new piece inserted (see Fig. 46). If the crack is under the fire bars, or at the joint of the furnace with the front plate, or in any part not subject to the action of the fire, the original plates need not be disturbed, but a covering patch fitted, as the increased thickness is not important in these positions (Fig. 47). Cracks in tube plates are sometimes met with, extending from one hole to another, or through several holes. These should be fitted with covering patches cut out to allow the tubes to pass through. The patch should be of sufficient area to take hold of enough of the sound tube plate to ensure that it is well held together across the crack, and it should be well secured by screwed bolts to the tube plate between the tube holes (see Fig. 48). A double patch may be fitted where considered desirable, one thickness inside and one outside the tube plate, keeping in mind the possibility of the increased thickness being objectionable (see Fig. 49). It may be desirable to add stays to the defective part. To avoid

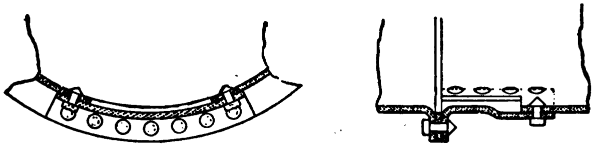

Fig. 46.—New Piece in Side of Furnace.

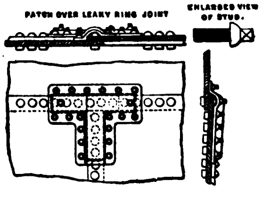

Fig. 47.—Patch over Leaky Ring Joint.

opening the crack when rolling in the tubes, the tube holes in the tube plate proper may be opened to clear the tube and the latter rolled into the patch, which must be firmly secured.

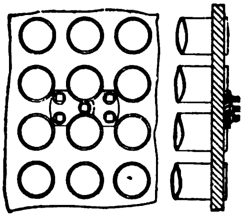

Fig. 48.
Patch in Cracked Tube Plate.

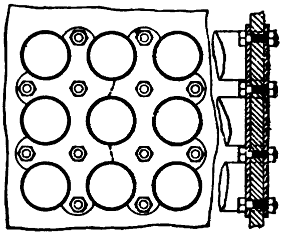

Fig. 49.
Double Patch over Cracked Tube Plate.

Laminations.—In iron plates laminations are sometimes found. When discovered, they should be examined by sounding the plate with a hammer, and by chipping or drilling to ascertain their extent. The laminated portions should, if possible, be removed, as unobserved decay may proceed between the surfaces; when small in extent they may be removed by chipping; when more extensive it may be necessary to additionally stay the plate after the lamination is chipped away, or, if very deep as well as extensive, the plate should be cut away and patched.

Thinning of plates may occur over a considerable area by general wear, or locally by pitting, or around stays, especially at screwed stays.

Plates thinned by general wear are usually fitted with additional stays. There is generally very little choice in the position for these stays, but it should be borne in mind that the original stays are placed in straight lines to facilitate cleaning the boilers, and the additional ones should be disposed, as far as circumstances will permit, with the same object in view. General wear of the kind indicated will be detected by the condition of the surfaces on both sides of the plate, by bulging, or by the drill test. Small isolated local pittings can (if they become very deep) be drilled out, the holes being stopped by screwed rivets. If the pittings extend over much surface, the plates must be additionally stayed. Continued thinning of a plate from any cause must, in most cases, eventually result in the plate being cut out and a patch or new plate inserted; but if the thinned part is not acted on by the fire, a covering plate may be fitted;

this must be of ample area and be thoroughly secured so as to efficiently act as a doubling plate.

The furnace or combustion chamber plates are often found thinned at the stay holes. This thinning is generally confined to a very small ring around the stay, and is often first brought to notice by leakage at the stay. To remedy this defect the stay should be removed, the hole tapped out so as to get the thread in a thicker part of the plate, and a larger stay fitted. The plate should be drill tested a small distance away from the plate to ascertain whether the thinning is confined to the vicinity of the hole. The process of fitting larger stays cannot be repeated more than once or twice, because the stays would become inconveniently large. In such cases, what is termed a "nut patch" may be fitted; a small circular covering patch is rivetted to the plate, the stay being screwed into this and rivetted over on the outside. Sometimes a boss is forged in the patch, the stay being then screwed through the boss and then rivetted over (see Fig. 50); in the event of leakage recurring at the stay it is then not necessary to unduly enlarge the hole, as the patch can be removed and a new one fitted.

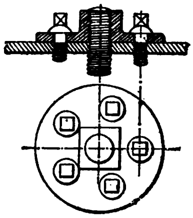

Fig. 50.
Patch Nut.

Patches.—No general rules can be laid down as to the type of patch to be fitted when one becomes necessary, so much depending on circumstances; but it will be evident, from the foregoing remarks, that care must be taken in patching the heating plates—(1) To avoid as much as possible a large increase of thickness of plates over any considerable area; (2) to so place the patch seams that they shall be affected by the fire as little as circumstances will admit, and to protect them where practicable by tiles or in other ways. In arranging patches it should be seen, in cases where three plates meet to form crossed-lapped joints, that the necessary thinning away, to enable the surfaces to come closely together, can be properly carried out; and, in all cases of rivetting, that the rivets can be efficiently "held up" during the process.

Stays.—A margin for wear is allowed in new stays; should the wear become great the stays must either be renewed or the number increased.

In some cases the renewal of stays, when the boilers are in place, requires special consideration. For example, the transverse shell stays of oval boilers cannot be drawn if several boilers are placed side by side. To renew these, each stay must be cut in two and taken out, and the new stay fitted in two parts and jointed, care being taken that the joint is not slack after the nuts are adjusted on the stayed plates.

Screwed stays to combustion chamber sides sometimes break in the water-ways (generally close to the plates), and unless they are specially constructed (*e.g.*, hollow stays) the fracture may escape notice. These stays should, therefore, be sounded by tapping the accessible ends with a hammer; broken stays may often thus be detected. When these stays require renewal, the holes are re-tapped and slightly larger stays fitted. To provide for such renewals, ships of the Royal Navy always carry several spare stays $\frac{1}{16}$ in. larger in diameter than those originally fitted, and taps to tap out the holes to suit.

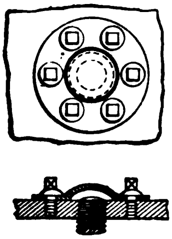
Fig. 51.—Patch over Leaky Stay.

Whenever portable stays are removed for purposes of examination, or cleaning, or for repair, they should be carefully examined by an engineer officer after replacement to ensure that the pin joints are properly connected.

A patch fitted over a leaky stay is shown in Fig. 51.

Tubes.—In modern "service" boilers stay tubes are screwed through both tube plates, the threads on the two ends of the tube, and in the two tube holes, being continuous. The ends of the tubes are pressed up, for screwing, so that the section at the bottom of the thread is not less than at the plain part of the tube. Plain tubes are jointed at the tube plates by means of expansion rollers. The joint at the smokebox tube plate gives very little trouble as a rule, but until a few years ago considerable leakage was often experienced at the firebox tube plate, especially when the boilers were being forced. When a tube leaks it must be re-rolled to tighten the joint. The rolling is performed by a roller expander, a sketch of which is shown in Fig. 52. It consists of a box containing three rollers, held so as to prevent movement in the direction of their axes, but permitting a certain amount of radial adjustment. A taper mandril passes through the box so as to press on the inside of the rollers. The box is inserted in the tube when in place, and the mandril is tapped in so as to force out the rollers against the tube. On turning the mandril the rollers are revolved, pressing hard at the same time against the inside of the tube, and so gradually tightening the tube into the tube hole in the plate. In the earlier mandrils the rollers were cylindrical, but when resting on the taper mandril, the surface circumscribing them was not cylindrical but conical, so that they tended to tighten the tube in the plate unequally along the length of the hole, the tube being hardest rolled at the outside of the plate. The expanders now in general use in the Royal Navy have their rollers tapered in an opposite direction to that of the mandril, the taper of the rollers being half that of the mandril, the object being that the expander shall roll cylindrically and tighten the tube uniformly in the plate. In the latest expanders the axes of the rollers are not parallel to that of the mandril (and tube), but set obliquely, to avoid the necessity of repeatedly tapping in the mandril. Such expanders are styled "self-feeding" expanders.

To assist in obtaining perfect joints, the tube ends where they fit the firebox tube plate holes are, when new, turned or ground to make a good fit in the holes before rolling.

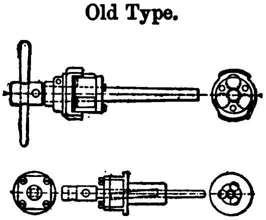

Fig. 52.—New Tube Expander.

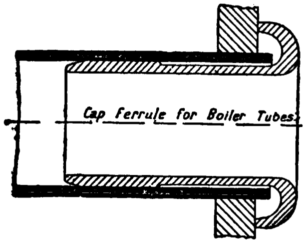

Fig. 53.—Cap Ferrule for Boiler Tubes.

Repeated rolling results in thinning of the tube ends, and it was formerly customary, when this had gone far enough, to drive slightly tapered malleable cast-iron ferrules into the tubes in order to protect and strengthen the ends. This is now only done in navy boilers with very small tubes, such as small steam-boat boilers, or in those carrying low steam pressures.

A few years ago the Admiralty, after trial, fitted the firebox ends of tubes of all Navy boilers carrying steam pressures of 90 lbs. per sq. in. and upwards with a special type of malleable cast-iron ferrule, now known as the Admiralty pattern cap ferrule. A sketch of this ferrule is shown in Fig. 53. It was fitted to stop leaky tubes by preventing the overheating of the tubes and tube plates at their joints. The cap protects the tube end from the direct impact of the heat, the face of the ferrule receiving the heat that would otherwise have affected the tube end. This heat is conducted along the ferrule into the tube at a certain distance from the plate, the ferrule being kept clear of the tube until the plate is well passed. The space thus formed between the ferrule and the tube provides a non-conducting "air space."

This fitting has been of inestimable value to naval tank boilers, and since its adoption leaky tubes have been very rare. Some ships, whose boilers were notorious, on account of the leakage of tubes occurring whenever they were forced, have proved reliable steamers since these ferrules were fitted. In most ships so fitted it is quite uncommon to have to roll a tube on account of leakage; and many ships go right through a commission without using their expanders at all.

It has been objected to these ferrules that they impede the draught and require a larger air pressure for full power; but in the case of tubes of 2½ ins. diameter and over this objection is probably unimportant. With the smaller tubes in use in locomotive boilers, difficulty is sometimes experienced on account of the partial choking of the tubes. A few observations regarding this matter may be of interest. It is seen that the action of the ferrule is to receive heat on its face and sides, and to conduct it into the tube at a certain distance from the plate; if this distance is long the ferrule will get hot, and in this condition "scoriæ" will after a time be deposited in the mouth of the ferrule. The longer the air space the hotter will the ferrule become, and the condition of the deposit will be such that it will tend to accumulate in a clinkery form, thus choking the tube. If the air space be shorter, the ferrule will keep cooler and therefore work clear, but there will be a greater risk of the tube joint heating and eventually leaking. The Admiralty made several experiments to determine the distance inside the tube plate at which contact between the ferrule and tube should commence, to avoid, on the one hand, hard, clinker-like accumulations, and on the other, possible leakage of the tube, with the result that the small tubes of locomotive boilers are fitted with ferrules having a somewhat shortened air space. Special cleaning tools are supplied in these cases to deal with the deposit. When first formed, the deposit is soft and can be removed by wire brushes; if it is allowed to accumulate it becomes more consistent, but can, up to a certain point, be cut out by rimer-shaped tools; both brushes and "spears" are worked through the furnace door. The deposit should be removed as frequently as possible while it can still be done by the brush, as the tendency to accumulate and harden increases with the existing amount. The extent to which the ferrules will heat depends largely on the efficiency of the contact at their junctions with the tubes; it is sometimes of advantage to take out the ferrules and clean both them and the tubes at the surfaces of contact. To provide for slight adjustments of diameter of the ferrules to suit the tubes, ships so fitted are supplied with expanding mandrils and reducing blocks. In the case of boilers with lower pressures than 90 lbs. per sq. in., it is clear from the foregoing remarks that cap ferrules could be fitted with advantage to any tubes that give trouble by leakage. Ships whose boiler tubes are so fitted carry among their stores a complete spare set of ferrules. When sweeping tubes with the ordinary hair brushes, the ferrules should be examined afterwards to see whether any have been pushed off the plate. Any so found should be knocked back, as otherwise the tube ends will not be shielded, and the surfaces of contact of ferrule and tube may be too close to the plate.

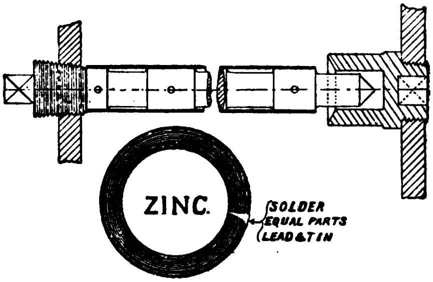

Fig. 54.—Bolt Stave for Torpedo Boat Boilers.

Tubes deteriorate by general wear, by pitting, and sometimes by splitting or cracking. Deterioration may, to a large extent, be arrested by the same means employed for other internal parts. Zinc slabs are placed for protection around the nests of tubes. In locomotive boilers, where a large number of tubes are placed close together, the zinc protection around the tubes is inadequate, and many torpedo boat boilers have been fitted with special zincs placed in the middle of the nests. The fitting is shown in Fig. 54. Tubes are removed here and there and replaced by bars resting on plugs screwed into the tube holes, these bars having rolled zinc wrapped round and secured to them. As the zinc wears the bars are taken out and the zinc is renewed. When boilers are empty, the practice of keeping them well warmed tends especially to the preservation of the tubes.

Tube Stoppers.—If it is not convenient to renew worn stay tubes, the requisite strength can be provided by passing bars through the tubes and nutting them on to washers or stoppers outside both plates.

If a tube should wear through by pitting, or from other causes, and removal is inconvenient, it must be fitted with a steel stopper fitting closely over, or into, each tube end, the stopper being secured by nuts on the end of a screwed bar which passes through both.

To remove a tube from a boiler, the firebox end is closed-in radially to enable it to be passed through the tube hole, a bar is put through the tube, and at the closed-in end a washer is secured on the bar, the washer being of such a size that it will shoulder on the tube, but pass through the hole in the tube plate. At the smokebox end the bar passes through a bridge or girder, the ends of the girder resting on the tube plate. The front end of the bar is also screwed, and a nut fitting over it bears on the bridge; on turning the nut the tube will be drawn out, the operation being assisted by tapping the bar at the firebox end. To facilitate withdrawal (and insertion), the smokebox tube hole is made $\frac{1}{16}$ inch larger than the body of the tube, so that when the fitting parts are out of both tube plates, the tube passes easily through the larger tube hole.

Stay tubes do not often require to be drawn (as plain tubes do for cleaning purposes); they are difficult to remove undamaged, and generally have to be cut out of the tube plates.

Splitting of tubes is generally caused by hard rolling, or by driving in tight ferrules. To detect tubes that have been damaged in this way, it is customary, when a number of tubes have been rolled and fitted with ferrules, to test the boiler twice—once to full test pressure after the tubes are fitted, and again to the working pressure after the ferrules are in place. For a permanent repair a split tube must be removed and a new one fitted, but for temporary purposes a bar and stoppers may suffice.

LIST OF SPARE GEAR CARRIED FOR TANK BOILERS.

Bearers for one furnace,	4 sets.
Bolts and nuts sufficient to remake one-half the whole of the joints of top doors, and for the end door joints of one boiler.	
Furnace bars for each boiler,	$\frac{1}{2}$ set.
Short screwed stays, $\frac{1}{16}$ in. larger than required when new, for one boiler,	$\frac{1}{2}$ set.
Stoppers and bars for tubes, one-twentieth the whole number of stay tubes fitted.	
Springs for safety valves, for one boiler,	1 set.
Taps with two single-handed wrenches for screwing boiler stay-holes for short screwed stays $\frac{1}{16}$ in. larger than required when new,	1 set.
Taps, plug, with single-ended wrenches for boiler stay tubes for each end,	2 no.
Tubes, stay, for boiler, one-fortieth the whole number of stay tubes fitted.	

CHAPTER X.

THE HULL AND ITS FITTINGS.

Water-tight doors* are fitted in water-tight bulkheads when it is necessary to provide a communication between the compartments. In small ships, where the distance from the lower compartments to the water line is not great, the only communication is over the upper deck, and no water-tight doors are fitted. This arrangement is found in all destroyers and, to a great extent, in the torpedo gunboats. In large ships, however, water-tight doors are fitted, which enable the engineer to go round the department at the level of the engine-room platform. Most of these doors are open under ordinary working conditions in harbour, and are closed promptly on the word being given. When a warship is cleared for "general quarters" all doors are shut and reported to the captain, who subsequently gives an order that necessary doors are to be opened, upon which the door between the engine-rooms and the doors between stokeholds on the same side of the ship are opened. When the doors are closed the engineers communicate with the stokeholds and between the engine-rooms by means of the voice pipes.

The water-tight doors at the level of the starting platform generally slide in vertical grooves; they are worked by means of a vertical screw which gears with a fixed nut on the door, and are always arranged to close by a right-handed motion. This screw shaft can be worked at the door and is continued to the main deck, where it terminates under a deck plate. When the deck plate is removed the door can be worked by means of a spanner hung in a rack adjoining. The door is attached, by a wire rope and pulley, to a counterbalance weight. It runs down very easily and can be opened more slowly by one man.

Between decks, below the water line, the water-tight doors slide in horizontal grooves, the weight being carried on rolling wheels; they are actuated by means of a pinion on a vertical shaft gearing with a rack on the door. These doors can be closed both from the main deck and at the doors themselves. Sliding water-tight doors run in wedge-shaped guides in such a manner that when closed the two faced surfaces of door and frame are jammed into close contact.

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* Water-tight doors should be situated as high in the compartment as possible (see papers by Lord Charles Beresford and Colonel Soliani, *Proc. of Inst. N.A.*, March, 1896).

When the door slides in horizontal grooves, a hinged flap is fitted over the bottom groove to prevent any material finding access and accumulating there; this flap is opened automatically by a plough secured on the foot of the door. In vertical doors there is generally no bottom groove, the bearing face is fitted a few inches above the deck so that there is clearance under the foot of the door when closed, and the foot of the door is held tight by the wedge-shaped side grooves.

On the decks above the water line the compartments communicate through doors revolving on vertical hinges. The doors have an india-rubber strip around the edges, and the edge of the frame is strengthened by an angle iron, the edge of which is jammed into the india-rubber by means of clips on the frame which are turned on to wedges fitted on the door. These clips should have handles on each side of the door, so that it can be opened and closed from either side.

In harbour, water-tight doors are worked, cleaned, and oiled once a week (see *S.M.*, Art. 498), the working party taking the doors between certain bulkheads on a fixed day. At sea, the doors in the department should be worked twice in the twenty-four hours, in certain fixed watches. It is necessary to inspect the door and see that it is properly closed when the deck indicator so registers. The party charged to maintain the water-tight doors in an efficient condition supply oil to the grooves and shafting and keep the doors so that they will close easily and completely; they also keep the indicator, to be described later, in a free working condition.

The sliding doors require little attention for their upkeep, but the grooves and surfaces must be kept clean. The india-rubber on the clip doors requires renewal at intervals. The clips must be kept free. The most common trouble with the clips is caused by the paint applied to the surface of the door for the sake of appearance. If all the clips are not worked on the appointed day, it may be found that some of them are jammed by the paint applied from time to time, and a quarter of an hour may elapse before the paint can be worked out of the joint.

No means of automatically closing all doors simultaneously has yet been approved or fitted for the Royal Navy. It is preferred that the men of the departments shall close the doors in their neighbourhood or on reaching the deck station above.

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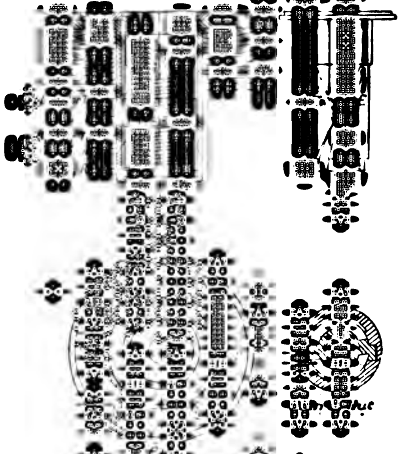

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[illegible] nd to work stiffly, [illegible] ould be examined [illegible] ed in these glands, [illegible] r used for washing [illegible] ant of lubrication. [illegible] shed through with turpentine followed by oil, and, if necessary, the packing should be renewed.

Ventilation.—The ventilation of the compartments of a large ship, below the armour decks, is effected by air trunks. The air is supplied by means of a fan drawing from a cowl, and is distributed through branch trunks. The hot air is withdrawn by means of exhaust trunks leading to the open air. Wherever these trunks pass through a water-tight bulkhead, an automatic valve is fitted, which will close the trunk should a compartment on either side of the bulkhead be flooded. The most common form of automatic valve is a flat plate attached to one arm of a hinged lever, which carries a large copper float at its other extremity, the whole being fitted in a casing on the air trunk. Should the casing be filled with water, the float swings up on the surface of the water and the flat plate fits on to its seating, thus closing the communication through the trunk. A chain is attached to the float, which can thus be occasionally tested by hand.

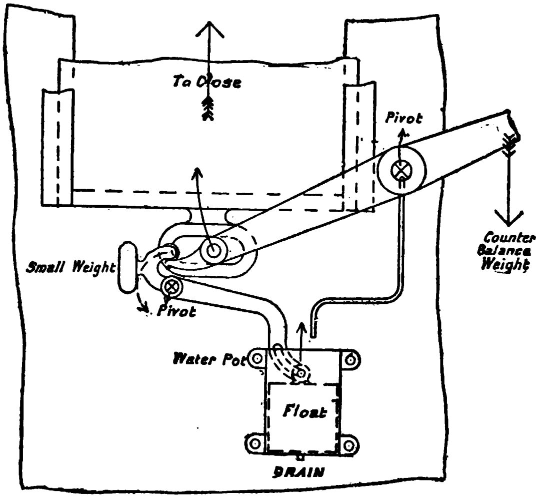

Fig. 56.—Beck's Ventilation Valve.

Beck's Ventilation Valve.—A form of ventilation valve (Fig. 56), giving a much larger opening, is described as follows:—The valve is a large flat plate sliding vertically in wedge side grooves, and is attached to one end of a lever, with a counterbalance weight on the other side of the fulcrum. This valve being opened, the lever is locked by a catch. The catch is freed by the upward pressure of a copper vessel, which is floated when the pot in which it is placed is filled with water; the counterbalance weight then swings down, and the valve travels up and is jammed, by the grooves, on to the faced surface. The pot can be filled from the further side of the bulkhead, by a small hole which is afterwards closed by the motion of the lever.

This mechanism is delicate, and all the parts must be kept scrupulously clean, otherwise the pressure of the float may not suffice to free the catch; the float then sometimes jams in the small pot.

Main Drain.*—The main drain of a ship is a large pipe running fore and aft along the bottom of the bilge, with suction tanks near each end of its length. It communicates with every compartment above the inner bottom—except the magazines—by means of small branch pipes and screw-down drain valves. Sluice valves are fitted on the drain pipe at its junction with the suction tanks. The main drain is generally in duplicate between the suction tanks.

The suction tanks can be pumped out by the steam bilge and fire engines, and also by the hand pumps. The interior of the main drain becomes very foul and dirty; it is flushed and pumped out every morning by means of a communication with the flooding system fitted at either end of its length. It is generally pumped out twice a day at stated times (see *Harbour Routine*).

Once a week the suction tanks are entered through the manholes and thoroughly cleaned out. The whole length of the main drain is swept by means of brushes drawn through by chains. The utmost care is required to prevent the state of the main drain becoming offensive. Whenever it is necessary to drain a compartment into the main drain, the screw-down valve should be closed immediately afterwards; otherwise dirty water may subsequently be washed into this compartment.

Flooding Valves.—In a warship a service of pipes is provided for the purpose of flooding each magazine, should such a course be advisable for the safety of the ship. The spirit-room, and the tanks containing the torpedo pistols, are included in the compartments which can be flooded. A group of magazines are supplied from one main flooding valve, which is in communication with the sea-suction valve of one of the hand pumps. Each separate magazine is flooded through a separate valve, fitted on a branch pipe of about 3 ins. diameter springing from the main flooding pipe supplying the group of compartments. All these flooding valves are locked and can only be opened by means of the proper key; they are worked by means of a spindle terminating under a deck plate in the main deck. The deck plate carries the lock and, when unfastened, a spanner can be shipped on the spindle; the valve can also be worked at a station just above the magazine, by means of a hinged spanner, which is carried on a loose collar on the valve spindle, and which is locked to the bulkhead by the same key that is used for the deck plate. It is, therefore, impossible for the magazine to be flooded accidentally. When the ship goes into action the whole of these flooding keys are carried by an engineer officer who attends on the captain, and a trustworthy petty officer is ready with the spanners required to work any particular flooding valve when an order is received to flood a magazine. The master flooding valve would be, on such occasions, opened previously in readiness.

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* The main drain was originally fitted in the double bottom, but experience has shown that it is exposed to a risk of damage in that position, should the ship take the ground.

Opportunities are taken to work all the branch flooding valves at short intervals to prevent the spindles from seizing. These opportunities generally occur after "general quarters" each week, when a responsible petty officer will be present in the magazine and will make preparations to catch any water which may drain out of the pipes.

Once a quarter all the flooding valves are tried with the main flooding valve on the system open; the chief engineer and gunnery lieutenant will generally be present. The water flowing through the pipe is caught in buckets, which must be in readiness. The branch flooding valves are opened wide and closed as smartly as possible, to prevent the passage of an inconveniently large quantity of water through the pipes to the magazine.

In order to provide a means of flooding the magazines when the ship is in dry dock, special pipes of about 6 ins. diameter are led down from a deck-fitting into the various main flooding pipes, with which they communicate through screw-down valves. A hood is fitted to the deck attachment, provided with branches on to which the hose from the shore hydrant are screwed.

The fire main consists of a large delivery pipe led right round the ship, below the armour deck; from this pipe branches are taken up through the decks, and water is supplied, at various stations, through a screw-down valve to the nozzle attachment for the hose. Screw-down valves are fitted along the length of the fire main, so that a burst length can be cut out during its repair, whilst pressure can still be maintained through the sound portion of the system.

All the hand pumps are fitted so that they can deliver into the fire main, through screw-down valves, and the delivery of each of the fire and bilge engines can be connected, or not, as required. It should be noted that the fire main pipe and the stand pipes of the hand pumps are independent, except for the short connecting branch.

The pressure maintained in the fire main, for washing decks and flushing purposes, is commonly about 25 lbs. At fire quarters, about 40 lbs. pressure will give a good supply to six or seven hose, if the communications with the latrines are shut off. A small leak in a fire main can be temporarily stopped by a band of india-rubber, secured by a clip (Fig. 57) around the pipe. A number of these clips of different sizes are generally preserved by the storekeeper. They are made of $\frac{1}{16}$-inch steel plate, with flanges about $\frac{3}{8}$ inch thick. When opportunity occurs, a patch is brazed over the hole.

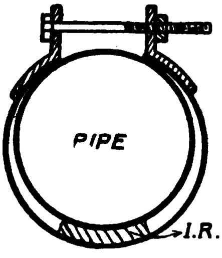

Fig. 57.—Clip for Plugging Small Hole.

The following method is employed by the officers of the P. and O. Company to remedy pin holes in the cast-iron pipes used for the hydraulic service, which are subjected to a pressure of 1200 lbs. per square inch:—

A piece of "sheet tin," about 4 inches long, is rolled into a cylinder of a diameter about 1 inch greater than the pipe. The tin cylinder is placed around the pipe, covering the pin hole, and the open ends of the annular space are filled in with loam. A hole is left in the top of the cylinder, and through this hole molten zinc is poured to fill up the annular space. A zinc band is thus cast around the pipe, and shrinks on cooling, so that it is firmly secured.

Hand Pumps.—In addition to the steam pumps a certain number of powerful pumps, worked by manual labour, are fitted in all classes of ships. These pumps are available whenever the ship is afloat, and are essential, since at times the fires are all out and the steam pumps cannot be used. The hand pumps are fitted to draw, through the foot valve, from a suction box, which latter consists of a casting containing a group of screw-down suction valves. These suction valves communicate, by means of pipes, with (1) the sea-suction Kingston valve and screw-down valve; (2) the main drain; and (3) various compartments of the D.B.

A pipe, fitted with a screw-down valve at each end, connects two suction boxes, and all the suction boxes are so connected that each pump can pump out any compartment of the D.B.

The suction pipe from the valve on the suction box contains a non-return valve, and the pipe runs down to a group of compartments of the D.B. Each separate compartment is pumped out through a branch suction pipe containing a screw-down valve, which acts as a non-return valve when half open, but, when fully open, a lower collar on the valve spindle keeps the valve off its seat. If it is necessary to flood any D.B. compartment to trim the ship, the sea-suction valve is opened out, the particular D.B. valve on the suction box is opened, the N.R. valve in the D.B. suction pipe is withdrawn by taking off the cover, and the branch valve to the particular compartment is opened wide. The water then runs into the compartment from the sea.

The hand pumps deliver directly overboard through a screw-down valve, and also to the various decks by means of a lead of "stand pipes."

A non-return valve should be fitted at the base of a long suction pipe, to keep the pipe charged full of water. If this valve be fitted, the pump will not have to clear the suction pipe of air on starting. A charging pipe, containing a screw-down valve, by means of which the suction pipes from the hold may be filled from the sea, facilitates the proper action of the pump on starting; in the system described above, the sea-suction valve and pipe can be used for this purpose.

Some few compartments in the hold do not communicate with the main drain, and can only be pumped out by the hand pumps. The following method is one of those employed :—A pipe, containing a screw-down valve, which is now opened out, is led from the delivery stand pipe to the intermediate pipe between two suction boxes; and a hose is led from the nearest nozzle on the delivery stand pipe to the compartment to be pumped out; then, by closing the delivery valve from the pump to the stand pipe, and opening the overboard delivery valve, the compartment can be pumped out, the stand pipe being now used as a suction pipe.

The suction valves for the different compartments of the D.B. are always fitted low down on the pipes close to the inner bottom, but they are worked from a higher level by means of long spindles.

The hand pumps are worked by a party of from four to about thirty men, according to the size of the pump. Portable cranks and brackets are shipped when the pump is required for use. The cranks are supported by the brackets and are attached to the shaft of the pump by cotters.

The leathers of the valves of a hand pump are apt to become dry, in which condition they are not air-tight, and consequently the pump may not heave; the best remedy is to fill up the delivery pipe of the pump with water, if it is above the water line; but, if the pump is below the water line, let it pump from the sea till the valves are in good working order. The foot valve, below the plungers, should be examined from time to time, and the leather renewed when necessary. The glands of all suction valves must be kept tightly packed, otherwise the air leakage may be great enough to prevent the pump lifting from the D.B. The lift of an atmospheric pump in good condition is about 25 feet on the average, the loss, 9 feet, being due to clearance spaces and friction.

The Double Bottoms.—This is the space between the inner and outer skin of a ship. It is divided into compartments by the longitudinal and transverse water-tight frames. Manholes are fitted, formed by raised neck pieces rivetted on the inner bottom, with covering plates secured by means of hinged bolts with butterfly nuts. Small screwed plugs are fitted in the longitudinal frame dividing the wing spaces from the double bottoms. The framing in the double bottoms is painted with red oxide of iron, a new coat being applied once in each quarter, if found necessary. Before the plating is painted, all signs of rust must be carefully removed. It is necessary to supply a current of air, from a portable fan, to dry the paint. The edges of the joints in the bottom plating, and the heads of rivets and all pockets are filled in with Portland cement, or pitch cement, to protect them from any accidental accumulation of water caused by leakage. The cement is mixed with a proportion of powdered coke or pumice stone, which is introduced to lessen the weight.

The chief engineer and the carpenter are jointly responsible for the double bottom spaces. The necessary work is carried out by a party under the control of a chief stoker, and drawn partly from the deck hands and partly from the stokers. These men receive extra pay, but they must not be employed for a continuous period exceeding three months, as the work is considered unhealthy.

If certain spaces in the hull are inaccessible for drying and painting, well-slacked lime is added to the bilge water.

All double bottom manholes are closed at sea, and the deck hands of the party are then employed, by the carpenter, in confined spaces other than the double bottoms or wings.

The following regulations should be strictly enforced on the working party:—

The double bottom to be entered should have its raised manholes opened at least twenty-four hours before anyone enters. The sluice valves between the upper and lower bottoms should also be opened, the plugs in the wings withdrawn, and the wing door opened, to increase the ventilation.

Before any man enters a D.B. or wing compartment, the engineer in charge should personally see that a lighted candle, lowered to the bottom of the compartment, burns steadily and fully for at least fifteen minutes, and the men should not enter until they have received definite permission through their petty officer. The party in a compartment should never be less than three in number, and constant communication is to be kept up with the outside.

The D.B. party are to be warned to leave a compartment directly the light begins to burn dimly. The work is to be performed with candles and not lamps, as the latter might be thought to burn dimly for want of trimming (see *S.M.*).

On no account are bogies of live coal or coke to be taken into confined spaces for warming or other purposes. If necessary, hot iron bars may be employed, after permission is obtained from the engineer in charge.

The following newspaper account of an accident which occurred in H.M.S. "Medea" will show the necessity for strict supervision :—

"Great consternation was caused on board Her Majesty's ship 'Medea' in Chatham dockyard, when it became known that four men who had been told off to clean the double bottom of the ship were missing. A search being instituted, it was found that the four men were still beneath the engine-room. A rescue party was formed, and two men were got out alive, but the other two were so swollen that they could not be got through the manholes. These were evidently dead. It has been ascertained that the men lighted a fire in a bogie, and took it into the double bottom for warmth. The dead men are a marine and a stoker. Workmen were set to cut away the plates to get the bodies out, and a doctor was summoned. The rescued men are in great danger.

"Later inquiries show that the men were engaged upon what is always considered to be hazardous work—namely, the coating of the inner bottom of the vessel with composition. The composition gives off an odour, even when used in the open air, but yesterday morning, the weather being cold, the men increased the danger by lighting a fire in violation of the regulations. When it was found that the men were missing, a search of the lower part of the ship was rendered impossible owing to the gas which filled the lower bottom. Numbers of seamen belonging to the Reserve gallantly attempted the rescue of their comrades, but were driven back by the overpowering gas. Admiral Morant, superintendent of the dockyard, found that the only possible way of a rescue was by clearing the vessel of foul air, and to carry out this work three powerful air pumps were applied. Even after these had been at work a long time, the men who gallantly volunteered were still obliged to retreat in face of the deadly gases, and all hands were ordered to withdraw. The pumps were again set in motion, and when the rescue party managed to get below, they found the unfortunate man Harber lying close to a manhole, but in such a position that it was necessary to cut away some of the gear to get the body out. The other man, Smeed, was found a short distance from his unfortunate mate, and the two others who were assisting in the work—a chief stoker and an ordinary stoker—were brought out in an unconscious state, but subsequently recovered."

Inner Skin.—The framing under the engines, boilers, and inner skin is protected by red oxide paint. Should any signs of corrosion appear, the *S. M.* directs that a little slacked lime should be placed in the bilges.

Reserve Feed-water Tanks.—Certain spaces of the double bottoms, usually those situated under the engine-room or stokehold, are now generally used for the storage of fresh water for use in the boilers. It facilitates the work of cleaning if these spaces can be emptied independently. The reserve tanks should be cleaned out at least once in three months, and all grease should then be removed.

The floors of the reserve tanks are coated with a layer of Portland cement, at least, 2 ins. thick. The side walls are not painted, but are protected by zinc slabs in immediate contact. The auxiliary feed pumps are fitted with suctions to these double bottoms; there is no connection with the hand pumps. The double bottom reserve tanks are also in connection with the feed-tank overflow, and with the boilers by means of a portable pipe.

Engine-room Telegraphs.—The dials in the engine-room are often connected with the pedestals on the bridge by means of bevel wheels on a line of shafting. Frequently this shafting runs over the tops of the boilers, and may work stiffly when the boilers are alight, owing to the longitudinal expansion caused by the high temperature. In some ships, expansion couplings are fitted to provide automatic adjustment. The bearings of the shafting should be rigid and of sufficient surface, otherwise grooves may be worn in the shaft and cause it to jam when slightly displaced. Lubricators are required on these bearings, and should be regularly attended—a point which is often overlooked if the lead of the shafting is difficult of access. Trouble is often caused by articles slung over the shafting in the mess decks; these articles may be drawn into the bevel wheels, and will temporarily jam the shafting. The engineer responsible should inspect the whole length of shafting previously to getting under way, and see that it is quite clear.* Paint is often recklessly applied in the neighbourhood of the bearings between decks; the engineer should, however, keep the shafting bright, if possible, and allow no paint to be applied. If the bearing is smothered in paint, a little turpentine must be worked through to wash it out. This remedy is particularly useful when shafting is seized by a deck gland. Oil should be applied after the turpentine has freed the shafting.

The above remarks apply also to the care of the controller shafting, connecting the steering wheels and the differential valve of the engine.

Voice Pipes.—These pipes should be hung on elastic brackets, so as to be insulated from the vibration of the structure. The author has found that the duplicate ear trumpets, connected to flexible tubes lined with india-rubber, are very liable to be damaged; and also that the india-rubber lining melts and obstructs the sound. Such connections are improved by substituting a single trumpet of large size.

Hints on the Use of Voice Pipes.—Speak slowly and distinctly when using the voice pipe, and do not approach the trumpet end so closely that the mouth touches it. In transmitting orders as to the number of revolutions required it is better to say "six, seven," with a slight pause between the two numbers, than "sixty-seven," because often only the last part of a compound number is distinct; if there is any doubt, count up to the number, thus, "forty, fifty, sixty," followed immediately by "five, six, seven," thus specifying the number required—viz., sixty-seven.

Always repeat an order received through the voice pipe, and if it has been correctly repeated the officer at the other end will say "right," to which "aye, aye" may be answered.

COAL BUNKERS AND COALING SHIP.

The coal bunkers are generally spaced around the engine-rooms and boilers, running both longitudinally and transversely. The walls of the longitudinal bunkers are formed by the inner skin of the ship, and by a longitudinal bulkhead running parallel to the inner skin. The length is divided up by the main transverse bulkheads of the ship, and also, in large ships, by intermediate transverse divisions. These bunkers open into the stokeholds through water-tight doors sliding vertically. The coal in the bunkers at the sides of the engine-rooms must be trimmed through water-tight doors, communicating with the after stokehold bunkers. The transverse bunkers are usually spaced between the engine-rooms and after stokehold, and between the forward and after stokeholds; the coal contained is, therefore, very handily placed. These transverse bunkers are fitted in long ships only.

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* In a recent (1898) order the chief engineer is directed to make this inspection personally.

Wing Spaces.—In the recent battleships and large cruisers the wing spaces are also utilised for coal. The spaces communicate with the bunkers by hinged water-tight doors, and the greater part of the coal must be trimmed through the bunkers to the stokeholds. These wing spaces are coaled through shoots, running downwards and outwards from the main deck. The bunkers of large ships in the Royal Navy are, for the most part, situated below the armour deck, and the bunker lids are of the same thickness as the armour deck. When bunker spaces are provided above the armour deck, they communicate with the lower bunkers by shoots, closed at the armour deck by thick sliding doors, and, at the bottom, by hinged water-tight doors, protected by screens and opening into the lower bunkers. The armour door at the top of the shoot is fitted in a small square compartment, into which several reserve bunkers open by means of hinged doors. The practice, when it is necessary to use coal from these reserve bunkers, is to trim down into the lower bunkers while in harbour, so that, at sea, the water-tight doors of the shoots may be kept closed. The same practice is carried out with regard to the coal in the wings.

It is not the practice to use up all the easily accessible coal before the reserve or wing bunkers are opened; on the contrary, a ready supply of coal is always reserved by the chief engineer for use in the event of orders being received to steam at full speed, in which event the men would be required on the fires and would not be available for trimming the coal from the remoter bunkers.

Painting.—Opportunity is taken when the bunkers are empty, to take up the floor plates and renew the cement protecting the lap joints of the inner skin plating, and also to repaint the sides of the bunkers with oxide of iron paint. The coal rubs this paint away and a new coat is supplied, as necessary, when the bunker is empty. Owing to the confined nature of a bunker space this paint dries slowly, and it is sometimes necessary to blow a current of air through, from a portable centrifugal fan, in addition to the ventilation supplied by taking off all lids and opening all bunker doors to the stokeholds.

A constant ventilation of the bunkers is maintained by means of air-supply trunks led from the upper deck to each bunker; they are terminated in the open air, by a revolving plate sliding over star-shaped openings, or by a gridiron sliding valve. These are known as "louvres," and are fitted with padlocks so that they cannot be accidentally closed. They are always kept open, except when a bunker is in use and the stokehold under air pressure. The bunkers are also furnished with exhaust trunks, which are led from the bunker to the funnel casing.

In addition to this system of ventilation, it is the custom to air the bunkers, for about six hours one day in each week, whenever the ship is in harbour, by removing the bunker lids. The lids must not be off whilst the decks are wet. The shoots must be kept clear of coal. If no ventilation trunks are fitted, the lids are removed four times a week, for not less than three hours at one time. The surface of the coal should be left 6 inches from the deck beams.

Fire-damp.—In spite of the above precautions accumulations of fire-damp occur in bunkers from time to time, more especially after coaling ship in wet weather. Consequently, whenever bunkers are opened, no naked lights are allowed in the neighbourhood of the doors, and, if a bunker is to be brought into use, all possible means are employed to ensure that it shall first be well ventilated. Safety lamps are used if a light is necessary for opening out, and they will indicate the presence of any combustible gases.

The temperature of bunkers not in use is taken twice in every twenty-four hours; any unusual increase of temperature should be immediately reported to the chief engineer. Special iron tubes, closed by screwed plugs in the main deck, are fitted, so that the thermometer can be lowered into full bunkers. The temperatures of bunkers in use are taken once in each watch and logged in the engine-room register.

Bunkers, immediately over or quite near the boilers, require special attention on account of the risk of overheating.

No rubbish should on any account be swept into, or stowed in, bunkers; oily waste is especially dangerous, being liable to spontaneous combustion.

Coal which contains sulphur, generally in the form of iron pyrites (FeS_2) is liable to spontaneous combustion, caused by the decomposition of the pyrites; the decomposition is accelerated by moisture. The heat of combustion of the pyrites, if not dispersed, may cause marsh gas to be given off by the coal, and the risk of an explosion must be guarded against by efficient ventilation Wet coals are, therefore, to be avoided, and ships are best coaled on dry days.

Coaling Ship—Disposition of Crew.—The method of bringing the coal on board varies with the locality. In Bombay, Port Said, and other eastern ports, the natives carry it in small baskets to the mouth of the coal shoots. In Malta and Gibraltar it is carried in baskets, from the ship's ports to the shoots, by the deck hands.

When coaling from colliers, the deck hands have to fill the bags in the collier's hold and hoist them inboard.

In every case, however, the coal is trimmed in the bunkers by the ship's stokers. In order to carry out the evolution smartly all available hands are employed. Coaling from a collier involves most work for the ship's crew. The disposition of the complement is as follows :—

The deck hands are disposed in the collier's hold and on the ship's deck, under the control of the deck officers. They fill the coal bags, man the whips, and transport the bags, when dumped on deck, to the coal shoots. The stokers available are disposed according to the capacity of the various bunkers. When trimming is necessary they work continuously inside the bunkers, in two relief parties. The leading stokers are disposed on deck, one to each bunker, to regulate the supply of coal at the shoots, so as to expedite the trimming. Care and experience are required to ensure that pockets, formed by shoots or casings; in the bunkers are filled up early, so that no delay is occasioned whilst packing such spaces; and for this reason it is advisable that each bunker should be trimmed by the same men on every occasion of coaling. The relief party of stokers on deck help to tip the bags and to drag them to the shoots. The chief stokers are in charge of a set of bunkers, to ensure that each receives an adequate supply. The skilled mechanics are employed in running the collier's winches, and the seniors among them tally the bags as they are dumped, and superintend the weighing of a certain proportion of bags—usually one bag in ten. The junior engineer officers are stationed so that they can supervise groups of bunkers and regulate the supply in such a manner that the ship is kept upright. They also take account of any bags lost overboard between the ship and the collier, and see that the loss is immediately brought to the notice of the officer of the watch and logged. The chief, assisted by the senior engineer, exercises a general supervision.

The above arrangements are made known to all concerned, by the senior engineer, who makes out the stations in readiness.

If a ship has to "break bulk" from a collier, the chief engineer examines the collier's holds when they are opened and reports that the condition is satisfactory and that the holds have not been opened for the use of the collier.

If a ship's company have to "sweep out" the collier, the chief engineer reports that the holds have been properly cleared.

The **following preparations** have to be made for coaling ship:—

An examination of the ship's bunkers must be made, and an estimate prepared of the quantity of coal required to fill each bunker.

The necessary coal shoots must be rigged in readiness; in a battleship this operation takes about three hours.

The coaling ports and fixed structural shoots must be opened out, and all portable screens for bunker doors should be seen to be in place.

A supply of coal must be trimmed into the stokehold, for the use of the auxiliary boilers, until a suitable bunker can be utilised. A bunker can be opened out, for this purpose, when it is filled above the level of the top of the water-tight door.

Stores Required.—The following stores are required, and must be mustered and stowed in a convenient place, under the storekeeper's charge:—

Coal bags; shovels, round-nosed and square, the former for use in the collier's holds; hanging lamps for use in the bunkers, these must be trimmed and filled; coal trucks for transporting the full bags to the shoots; a few stout fire slices; and some heavy sledge hammers to clear choked shoots and to break up large lumps.

Report.—The following particulars are given of the coaling of H.M.S. "Sanspareil" from a collier at Poros, 21/11/94; a collection of similar records should be made:—

Collier S.S..................came alongside at 6.45 a.m., 4 winches in use.

7 a.m., started coaling.
7 to 8 a.m., received 72 tons.
8 to 9 ,, ,, 87 ,,
15 minutes' stand easy.
9 to 10 a.m., received 56 tons.
10 to 11 ,, ,, 96 ,,
11 to 12 noon, received 80 tons.
12 to 1 p.m., went to dinner.
1 to 2 ,, received 64 tons.
2 to 3 ,, ,, 50 ,,
3 to 4 ,, ,, 45 ,,
4 p.m., finished coaling.

Total quantity received, 555 tons; total working hours, 7¾. Stores employed—200 bags (2 cwt.), 47 round-nosed shovels, 20 trolleys, 4 hammers, 4 mauls, 4 slices, 2 spring balances, 2 hand spikes. The above performance, good at the time, has since been greatly exceeded by ships of the "Royal Sovereign" and "Majestic" class using Temperley transporters. As much as 175 tons has been taken in during each of two consecutive hours; and a total quantity of 775 tons at the rate of 160 tons an hour.*

After Coaling.—After the bunkers are filled the following duties have to be carried out by the engineers:—

All means of ventilation are placed in operation.

The lids of shoots on the upper deck are jointed with a mixture of white lead and tallow, and made water-tight.

The coal shoots are taken down, swept, and properly stowed in their assigned positions.

The men employed in the bunkers are mustered.

Stores are mustered, surveyed, and returned to the storekeeper, and the chief engineer is informed of any losses or damage incurred. The coal bags must be well shaken out; those broken are set aside for repair. The commander generally lends a party of deck hands for the sewing work required.

The quantity of coal received is estimated from the average weight deduced by the weighing operations, and from the total number of bags received. The 2-cwt. bag itself weighs from 12 to 13 lbs., and commonly scales about 230 lbs. when well filled.

The Temperley transporter facilitates the operation of coaling ship from a collier; these appliances are now carried by certain ships of the Fleet, and are lent to other ships when ordered by the admiral in command. The following sketches of details and description were given in *Engineering* of 15/11/95. The appliance consists essentially of a beam or spar, which can be hoisted and supported from a suitable hook. A traveller runs on a rail attached to this spar and carries a skip or bags. This traveller can be stopped at any one of a large number of points along the rail, and the skip lowered and raised. When the load is being lowered, the traveller is rigidly locked in its ways; and when it is travelling the load is locked, so that it cannot be lowered. The whole of the various motions of lowering and travelling are controlled by a single wire rope passing over the pulley at the end of the spar. The spar is stayed, at frequent intervals, by a series of wire-rope stays, which, at their upper ends, are connected by a single ring. The whole appliance can thus be slung, if desired, from an ordinary derrick or crane, and, when employed on shipboard, it is not mounted till just before

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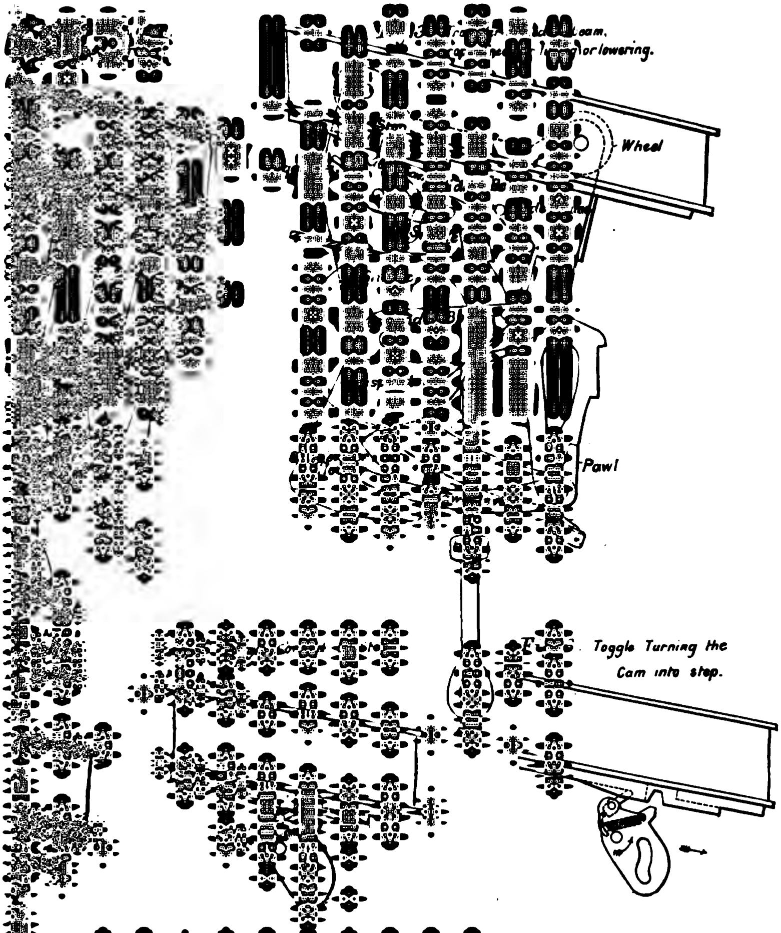
* "Magnificent" coaling from Collier, 29/11/97.

PLATE IV.



... or lowering.

F... Toggle Turning the Cam into step.

use, being secured on the deck until wanted. The ends of the spars are stayed to fixed points, and when all is hauled taut, the transporter is sufficiently rigid.

The various parts of the Temperley transporter should be mustered and inspected on the day previous to coaling; all lubricators should be filled and the pawls worked.

In the example erected at the Midland Coal Company's Wharf, Woolwich (Plate IV., Fig. 1), the spar is 85 ft. long, and can be traversed along its supporting beam a distance of 40 ft., so that a very large area is commanded by the skip. The rail on which the traveller runs is made out of a channel-iron, and is fitted with stops at intervals of 5 ft. All the stops, save the one at the lower end of the spar, are under control, the skip only being stopped at them if the engineman so desires. The one at the end is, however, so constructed as always to stop the traveller there. The construction of the traveller, permitting all these operations to be performed by a single rope, is shown in detail in Figs. 2 to 6. In Fig. 2 the traveller is shown free to move down the beam, whilst in Fig. 3 it is locked, and the load can be raised or lowered. Assuming the traveller locked, and the load to be raised, the ball shown in Fig. 3 strikes against the pawl lever, and, raising the pawl, frees the suspender hook. This hook is then moved round by the continued motion of the ball until the suspender bolt enters the gab of the single cam, causing it to rotate. By means of a sliding bolt the motion of this cam affects the double cam, rotating it so as to withdraw the catch from the notch shown on the bottom side of the beam. The traveller is then free to move, the parts being in the position shown in Fig. 2, and the load, as will be seen, is carried on the suspender hook. The above cam action has the peculiarity that when in the position shown in Fig. 2, motion can only take place by actuating the double cam; and whilst in the position shown in Fig. 3, it can only take place by actuating the single cam. In the position shown in Fig. 2, the traveller can be moved either up or down the beam without difficulty. In the latter case the toggle shown at the top of the double cam clears the stops without difficulty; but if the motion is upwards this toggle strikes against the back of the stop, as shown in Fig. 4, and is turned over into the position shown in Fig. 5. If now the traveller is again allowed to slide down the beam, this toggle catches, as shown in Fig. 6, and moves the double cam round so as to engage with the stop. This motion of the double cam at the same time turns the suspender hook by suitable linkwork into the position shown in Fig. 3, in which the traveller is locked, whilst the load can be raised or lowered. In working, the skip is run out to the end of the spar, where the traveller always locks itself, there being a specially deep stop there. The skip is lowered and filled, then hoisted till the ball unlocks the traveller and locks the load. The skip is then traversed up the beam past the desired stop, and allowed to go back, when it locks itself, and the load may be lowered. On raising the skip again, the traveller is unlocked, moved slightly up the beam, and allowed to run down again to the lower end, when the former cycle of operations is repeated.

CHAPTER XI.

CLEANING, PAINTING, AND PRESERVATION OF MACHINERY.

The materials generally used for cleaning are—whiting, soft soap, disinfectant powder, hard soap, soda, bath brick, blacklead, kerosene or paraffin, turpentine, emery cloth, burnishers, oakum, cotton waste, &c.

Taking the materials in order:—

Soft soap is used for washing linoleum, decks, and rough paint surfaces. It will spoil good paint surfaces, as it renders them thin and dingy. It does not leave a very white finish on the decks, and should only be used for rough purposes. Clothes washed with soft soap have a disagreeable odour.

Disinfectant powder is more powerful than soft soap. It is used for removing grease stains from boards or corticene, but should not be employed for painted surfaces. It should be applied and left to dry on the deck, at the part stained by grease.

Hard soap (common yellow) is more expensive than soft soap, but is greatly to be preferred for painted surfaces and for white decks. It should be dissolved in warm water and not rubbed over the paint work. A soft flannel should be used. Paint work should be thoroughly rinsed after being washed.

Soda is dissolved in warm water and used with soap for washing out grease marks.

Bath brick dust is used for polishing rails, rods, and metal surfaces. It should be used with great care, so that none obtains access to bearings. The men will often use the empty lubricators as receptacles for their brick and cleaning rags. This practice should be punished when detected. The brick dust should be rubbed to a very fine powder before being applied, as it then produces a much better polish.

Black lead, mixed into a thin paste with a little kerosene, is used to impart a black finish to surfaces subjected to heat which cannot be painted; the kerosene evaporates and leaves a black shiny surface. Blacklead is also used for cold surfaces, such as floor plates and ladders; care must be taken to put it on very thin, or it will be trodden about the decks.

Turpentine is used to clean dirty paint work, which it does by dissolving the paint.

Emery cloth must be used with discretion, and care must be taken to protect adjacent working surfaces from the grit.

Burnishers are to be recommended, those formed of chain links on a leather pad about 4 inches square are best. They leave a beautiful finish on bright work previously cleaned with brick dust.

It is generally necessary for the engineer in charge of a department to provide burnishers and a certain amount of emery cloth, and the practice encourages the men to take a proper pride in the appearance of the machinery.

Preservation of Bright Work.—When bright work is to be left for some time without attention it is smeared thoroughly with a paste of mineral oil and white lead, which is easier to remove than a surface of paint. The same practice is followed for long runs under steam.

Spare gear, which is to be bolted in racks, is painted first with a coat of red lead for preservation, and afterwards with a coat of white lead. Bright work should be kept well oiled, except when it is cleaned for the periodical inspections (Art. 121, *Steam Manual*).

No part of the machinery which can be kept polished should be painted; this rule will benefit both the appearance and durability of the machinery. It is usual, in H.M. service, to constantly work to this end, throughout a commission, by gradually removing the painted surfaces and replacing the paint by polish. The condition of polished machinery is evident to the eye, whereas painted machinery may be gradually eaten into by rust. For this reason it is necessary to take down, clean, and examine all the spare gear as often as possible, say at an interval not longer than twelve months. The paint should be scraped off, the surfaces polished, so that all rust is removed, and then the surfaces should be painted afresh, and the gear secured in the racks provided.

No whitewash is to be, on any account, used on any portion of the iron or steel frames, outside plating, lower parts of bulkheads, inside plating, or other works in the holds of vessels, and in no other case is whitewash to be used on ironwork, unless the iron be first well coated with paint (Art. 563, *Steam Manual*).

The composition of whiting is about 95 per cent. calcium carbonate, 3 per cent. silica, and 2 per cent. of water.

Painting.—Before painting a surface it should be thoroughly washed to remove all grease and dirt. If soda, or disinfectant powder, is used in the washing, all the alkali should afterwards be removed from the surface by rinsing it with clean water.

The surface should be thoroughly dried before the paint is applied, otherwise the evaporation of the moisture will form blisters.

The surface of the old paint should be smoothed down with pumice-stone or sand-paper before the paint is applied.

The drying of paint is, to a certain extent, dependent on the temperature; paint exposed to a temperature of 120° F. will dry in a few hours if situated in an open space.

Blistering is caused if the inner coat be thick, and still wet, when the outer coat is applied.

Paints and Varnishes.—The ordinary paints used in the engine-room department are—Red lead, red iron oxide, white lead, zinc white, ordinary black, japan black, yellow ochre, engine green, &c.

Red lead paint consists of a mixture of two oxides of lead. It is prepared by roasting metallic lead till the protoxide is formed, which latter is then heated in a reverberatory furnace until the right colour is obtained. It is a permanent paint, except when acted upon by sulphur or sulphides.

Red lead mixed with boiled linseed oil is the most generally used paint for coating metallic surfaces exposed to damp—such as engine bearers, boiler bearers, the exposed bottoms and fronts of boilers, bilges, pipes in bilges, propeller shafting, funnels, spare gear, &c.

The paint acts as a preservative against rust, by protecting the metallic surface from contact with water. It is essential that the surfaces should be scrupulously cleaned and dried before the paint is applied.

Men should not be employed for a longer period than two days in painting with red lead, nor should they be forced to undertake such work (see Art. 576 of *S.M.*).

Red oxide of iron is used to coat surfaces and preserve them from rust. It is applied in confined spaces, such as those of the double bottoms and wings, where the use of red lead is prejudicial to the health of the men applying it. Surfaces coated with iron oxide are sometimes sticky, owing to the want of sufficient driers. The paint should be mixed with boiled oil, and the driers should be added by an experienced man. All paints require careful mixing and a considerable amount of stirring and working.

Compartments painted with oxide should be specially ventilated in order to dry the paint.

Red oxide paint of a brown-red colour is prepared from the native hydrated oxide (Fe_2O_3), which is ground up in a wet mill. To obtain a brighter red the oxide is calcined to effect dehydration. When the requisite shade is obtained, the charge is drawn from the furnace and allowed to cool.

The precautions to be observed, in order to preserve the health of men engaged in painting, are laid down in Art. 576 of the *S.M.*:—"The working clothes should be of canvas and not of woollen material, and should be washed at least once a week. The hair and body should be washed several times a day. A mask of muslin, or bunting, may be used over the mouth. Plenty of fat or oily food should be eaten.

"A sulphuric acid orangeade drink is a good preservative. It is thus made:—

Diluted sulphuric acid, ...	1½ oz.
Concentrated infusion of orange peel, . . .	1½ oz.
Syrup of orange peel, ...	5 fl. oz.

Mix with two imperial gallons of water.

"A large wineglassful to be taken for a draught, mixed with water according to taste.

"The use of this drink should be compulsory.

"The men should appear before the medical officer not less than once a week."

White lead is carbonate of lead. It is made by exposing lead plates to the combined action of vinegar and carbonic acid gas. The plates of lead carbonate are ground in water to a fine powder.

White lead is used for bulkheads, as a reflector and to preserve a good appearance. The sulphurous gases generated by bilge water and heat have a speedily injurious effect on its appearance. A temperature of 200° F. causes white paint to lose its elasticity and become brittle.

Wet surfaces of white lead are prejudicial to the health, and men should not be continuously employed in such work (*Steam Manual*, Art. 576).

Zinc white consists sometimes of pure oxide of zinc, formed by volatilising the metal; the vapour of the zinc unites with oxygen and a white powder is deposited. This paint is less poisonous, but also more expensive, than white lead.

Another zinc white, produced by the "Griffith's" process, is an oxysulphide of zinc; it is not so expensive as the zinc oxide and has as good a covering power as white lead. It is dearer than white lead, but resists the action of the weather better, and is therefore said to be more economical.

Zinc white, mixed with a certain proportion of varnish, has a far better and more lasting appearance than white lead. It can be used as a top coat, and gives a good finish to engine columns, and to the approaches to the engine-room which have good daylight upon them. Paint mixed with varnish dries rapidly. To produce a very smooth surface, successive coats must be applied and rubbed in by pumice-stone.

Black Paints.—All black paints owe their colour to carbon, which is obtained by carbonising organic matter, particularly bones. The carbon produced should be free from oily matter, since this latter reduces the drying properties.

Ordinary black is used for the lower portions of engine-room columns, and generally to show up the white surfaces painted with white lead or zinc white.

A good serviceable method of painting engine-room bulkheads is to mix a French grey—using black paint and white lead—and apply it to a height of, say, 4 ft. all round the engine-room. The upper part of the bulkhead is painted white and separated from the grey by a band about 3 ins. wide of red or black paint. The French grey is more lasting if "granited." This is done by dipping a stiff nail brush, or a small bundle of fibres, in red, black, and white paint successively, and throwing small spots uniformly on the grey ground by drawing the finger across the fibres of the brush. If well done, a "granite" surface looks better than the clean grey ground, and shows fewer dirt marks, but, carelessly done, its appearance is smudgy. The paint is more durable if protected by a top coat of varnish, and can then be washed with soap and water without injury.

Black funnels are treated by first coating the clean metal surface with boiled linseed oil, and afterwards applying a coat of very thin black paint. The great heat to which some funnels are exposed makes it necessary to renew the black coat frequently.

Japan black is prepared from asphaltum, linseed oil, red lead, litharge, and copperas. It is a varnish.

Japan black imparts a more finished and smoother appearance than ordinary black, but it is usually supplied in very small quantities to the engineer's stores.

Modern Brunswick greens consist of a white pigment (sulphate of baryta) as base, coloured by Prussian blue and chrome yellow. They are fairly durable, but are notably darkened if acted upon by sulphur or SH_2. Sometimes a small quantity of gypsum and lead sulphate are present in this paint.

Engine green is supplied ready mixed. It is the best paint to use for hot surfaces, such as the tops of cylinders, because it resists the action of heat far better than the other ordinary paints supplied.

Scheele's green is composed of 1 part of powdered arsenious oxide (white), and 2 parts of potash (carbonate of potassium), dissolved by boiling in 35 parts of water; the solution is filtered and poured into a solution of 2 parts of copper sulphate as long as a precipitate continues to form. The precipitate is collected, washed, and dried at a gentle heat.

Heat decomposes all the copper greens.

Yellow Ochre.—The canvas covers of steam pipes, when lagged with felt, are usually painted with yellow ochre mixed with boiled linseed oil; the paint will usually last as long as the canvas, and preserves the latter.

This pigment consists of an earthy base coloured by oxide of iron, or oxide of manganese, or both.

Yellow funnels are treated by first coating the clean-scraped metal with boiled linseed oil or red lead, and, when this coat is dry, applying a coat of yellow wash of the following composition:—

17 lbs. yellow ochre.
50 " whiting.
2 " glue.
1½ pints boiled linseed oil.
2 or 3 candles.
Water as required by shade.

The whole to be allowed to simmer for two hours and to be continually stirred. This mixture gives a rather light colour.

Yellow wash is best applied when the funnels are cold, otherwise it dries too quickly and is patchy.

The framing used to carry the men should be thoroughly examined before use by an experienced mechanic, as should also the hoisting chains, and the top pulleys and bolts secured to the outside of the funnels; these fittings are exposed, and have been found wasted by rust.

The same composition of yellow wash may be effectively used for the lower parts of the casing over the boilers, which are exposed to view. The iron surfaces must first be coated with red lead to protect them from the wash.

Linseed oil is obtained by crushing the seed of the flax plant. It is never pure because the seed is always mixed with that of the cotton plant, or with mustard and colza seed.

"Boiled" linseed oil is obtained by heating the raw oil to a temperature of about 300° to 400° F. with metallic oxides called "driers," usually litharge or red lead. Linseed oil dries by oxidation, and the oxides added act as driers, both by giving up their own oxygen and, more actively, by facilitating the combination of atmospheric oxygen with the oil.

Boiled linseed oil dries much more rapidly than the raw oil, and leaves a hard lustrous coat. As a vehicle for paint, raw oil is added to the boiled oil, because the former, used alone, leaves a coat or skin, deficient in elasticity and liable to crack. Boiled linseed oil is sometimes called oil varnish; used alone it is too porous to thoroughly protect metal surfaces.

Few oils are capable of being used for painting; in fact, only such as possess the property of "drying," and becoming hard when exposed to the air. The following list includes the best:—

Linseed oil, poppy seed oil, weld seed oil, menhaden oil, hempseed oil, tobacco seed oil, walnut oil, Japanese wood oil.

In addition, cottonseed oil and rosin oil may be mentioned as possessing weak drying properties.

Linseed oil is the only oil in general used for painting; if boiled with caustic soda it is decomposed, forming soap and glycerine.

Turpentine is a resinous exudation from certain species of pine trees.

Varnishes may for practical purposes be classified as—(1) natural varnishes; (2) oil varnishes; (3) spirit varnishes; (4) water varnishes.

The first comprise the natural lacquers of China, India, and Japan; they issue from the tree in a liquid form.

Oil varnishes are made from resin, linseed oil, turpentine, and some spirit. The process comprises melting the resin or gum, boiling the oil, mixing the melted gum and boiling oil, boiling the varnish, thinning the boiled varnish, and clearing.

Freshly-made varnish is unsatisfactory in use; it requires to be kept in large iron tanks from six months to two years, during which time the insoluble constituents settle down.

The ingredients of Japan black have been mentioned; the ingredients used for Brunswick black are the same, but the varnish is thinned with turpentine.

Spirit varnishes are prepared by dissolving resins in methylated spirits, by the aid of heat or otherwise. On drying, the film tends to contract, and the resin being brittle, the varnish is apt to crack.

Varnishes differ from paints in giving a transparent lustrous coat capable of resisting the destructive action of the weather.

Oil varnishes, properly mixed, neither expand nor contract on drying.

Pitch, of extreme hardness, can be obtained, which (if carefully softened by the addition of creosote oil and then dissolved in one of the cheaper light oils, or in some corresponding product of petroleum), yields a varnish which, when used for the protection of ironwork, gives very satisfactory results. If this protective be used, a coat of boiled linseed oil should be applied to the clean surface of the iron, and afterwards, when perfectly dry, should be covered by a coat of the pitch varnish.*

The following article is abridged from *Engineering*, May 14, 1897:—

The Painting of Metallic Structures.—In spite of all care, corrosion takes place, and each time the protective coating is renewed a great amount of rust has first to be removed. It seems to be impossible to prevent iron—and more particularly steel—from rusting. Engineers, as a rule, know little of the chemical aspect of paints, and have to rely on their practical experience to guide them. It requires a highly-skilled chemist even to guess at all the changes which take place in a coat of paint.

Mr. A. H. Sabin, formerly professor of chemistry in the University of Vermont, America, has made important experiments on this subject. There was a time, he says, when nearly all the bridges of America were painted with powdered pigment, usually a metallic oxide, or carbonate, suspended in linseed oil. These paints are durable on wood, but experience shows that the oxide acts as a carrier of oxygen to the underlying iron, causing it to rust. Furthermore, linseed oil makes a porous coating, through which moisture can penetrate, and is also easily attacked by sulphur compounds. Hence this class of paint has been mostly abandoned, for structural work, particularly when it contains iron oxide. Iron oxide for paint is, usually, either a mixture of iron oxide (Fe_2O_3), with 30 to 70 per cent. of clay, or is made from granular ore, which may be ground to a powder without much difficulty. These soft ores contain hydrated oxide, which is identical with the principal constituent of iron rust, and it is believed that the particles form centres of rusting on the surface to which they are applied.

The chemical problems involved in the use of paints, having red or white leads as pigments, are obscure. The lead probably combines with the oil to form a soap, the acid of the oil uniting with the lead of the oxide to form a salt. The addition of lead compounds to oil increases its rate of drying, whether heat be used to combine them or not. White lead is converted, in time, into a crumbling soap which washes off.

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* For further information on Paints, see *Painters' Colours, Oils, and Varnishes*, by G. H. Hurst, published by C. Griffin & Co.

The quality of a paint depends greatly on the oil. The best quality of linseed oil is obtained from pure seed, by pressure at a not very high temperature. The oil is thus obtained mixed with some watery and vegetable matters, from which it separates on standing. If it be stored in a warm place from one to three months a considerable sediment settles out, leaving the oil bright and clear. Often, the linseed contains a large proportion of foreign seeds and the oil is a mixture from the beginning.

"Boiled oil," Mr. Sabin tells us, does not mean anything definite. The old practice was to put linseed oil in a kettle and heat it to 400° or 500° F. The heat was only sufficient to attack the foreign vegetable matters in the oil, and at that point some lead and manganese compounds were added, which combined with the oil, making it darker in colour, heavier in body, and much more active in drying. All such oils are, we are told, inferior in durability to pure raw oils, for every bit of drier added to oil lessens its permanence. It is supposed that the oxides act as carriers of oxygen, enabling the oxygen of the air to combine with the oil; and their injurious effect is ascribed to their enabling the oxygen to continue its action on the oil after the latter has absorbed the normal amount. "Boiled oil" is now commonly made by adding a few gallons of liquid Japan drier to every barrel of raw oil. In the way of adulteration 30 to 50 per cent. of fish oil, liberally treated with driers, is used; and sometimes a mixture of mineral oil, resin, and driers, equal to one-third or one-half the whole, is added to the linseed oil.

Another class of paint consists of asphalt (mineral pitch), or other bitumen, dissolved in turpentine, benzine, or other fluid. Asphalt is a class of minerals intermediate between the petroleum oils and bituminous coal. Such paints often contain resin, which is detrimental to everything but appearance. Some of these are true oil varnishes, properly combined with linseed oil, and these are very durable.

Mr. Sabin holds that the maximum of durability is only to be reached by a compound of hard asphaltum, copal gum, and linseed oil, thinned, if necessary, with pure turpentine. The oil must be pure, and should be so refined as to have its non-drying constituents removed, in order to avoid, as much as possible, the use of driers.

Such a compound as the foregoing satisfies very well the requirements of a paint for metallic surfaces.

A coated metal surface can be improved by baking or "stoving" it. A familiar instance is found in bicycles. The paint or varnish hardens into a glass-like surface, which resists hard usage and the effect of weather in a wonderful manner.

Cement.—Portland cement is made by burning chalk in order to expel the carbonic acid, the lime so formed being then ground up with clay (*silica*) to a fine powder. If kept in a damp place, cement will cake, and undergoes chemical changes; it is only the impalpable powder that possesses cementing properties. Cement should be turned out of the cask and exposed to the air, just before use, in order to slake the free lime; it then absorbs water and the powder increases in bulk. The strength of cement increases with the time after setting, up to a certain limit; the tensile strength is about 350 lbs. per sq. in. at the end of seven days.

The composition of the black or pitch cement, sometimes used for the preservation of the hull plating, is as follows:—Mineral pitch, 250 lbs.; mineral tar, 6 gallons; Roman cement, 360 lbs.; fine white lime, 56 lbs.; fine rosin, 14 lbs. It is lighter than Portland cement, but will run if exposed to a high temperature, for which reason it is not employed on the plating under the boilers. It should not be used in confined spaces, as it is injurious to the men employed in its application. The directions for its preparation are as follows:—Boil the pitch and tar, add cement in small quantities and mix thoroughly; add the lime and rosin in a similar manner. When well mixed boil for eight hours. The surface of the plate to be protected should be well washed and dried, and then coated with a varnish made by boiling mineral tar for eighteen hours.

Coal tar is injurious to iron surfaces on account of the ammonium salts and carbolic acid it contains.

CHAPTER XII.

RECIPROCATING PUMPS, FEED HEATERS, AND AUTOMATIC FEED-WATER REGULATORS.

RECIPROCATING PUMPS.

The type of pump known as the "Keyham pattern," now nearly obsolete, requires considerable attention, chiefly caused by the wear of the crosshead brasses, which require refitting about once a month. Liners should be secured to these brasses by rivets with countersunk heads, in addition to a soldered joint; the main bearings and eccentrics also require lining up from time to time. The pump-rods tend to wear taper, and the pump glands then leak; these rods are often made of steel covered with a sleeve of gunmetal, the plunger being secured by a cap-nut, which must be well jointed to prevent water obtaining access to the steel rod. The pump-rods are also made of solid gunmetal, of equal strength to the covered rods, but of larger diameter, with a T-head bolted to the steel crosshead. These rods have a considerably longer life owing to their increased bearing surface. Those pumps employed as feed-pumps often have metal valves (Fig. 58), which wear well and are generally satisfactory. Those fitted as salt-water pumps, for the bilge and fire service, are run at a faster speed and have flat india-rubber valves.

Corrosion.—Instances of very rapid corrosion of the barrels and valve seatings have occurred in these salt-water pumps; the barrels have sometimes been eaten through in a week. The cause has been attributed to a rapid galvanic action set up by leaks in the electric circuits of the ship. The copper suction and delivery pipes have also rapidly deteriorated in some cases, particularly when the pipes are placed in the bilges. For this reason zinc plates* (Fig. 59) have been introduced, placed in special boxes inserted in the length of the pipe. The zinc plate is suitably bolted to the cover of the box, so that it can be easily

* In later practice mild steel plates are used.

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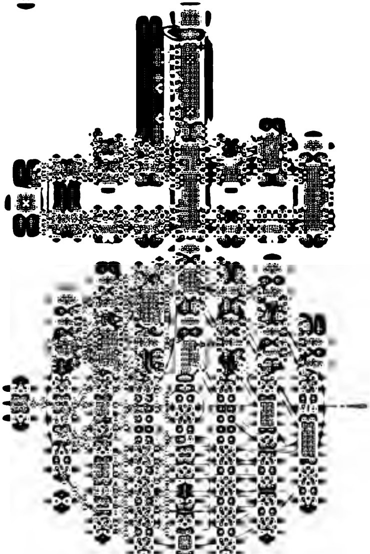
[illegible] rs to fall off when [illegible] 4*a* are very liable



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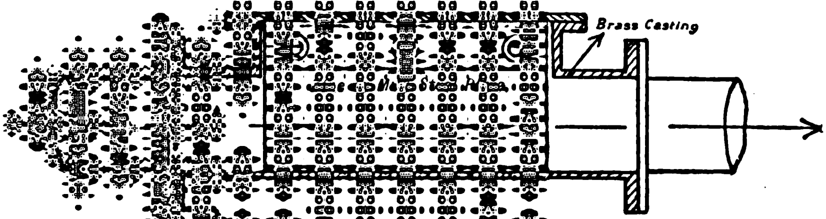

[illegible] Piping.

[illegible] m away; the repair [illegible] work to fit it.
[illegible] stos or india-rubber [illegible] tton soaked in hot

tallow, answers best for the pump glands. **The pistons** have cast-iron spring rings and give little trouble. **The plungers** are packed with gun-metal rings. A single broad ring lasts longer, and is to be preferred to narrow rings fitted in divisions of the packing space. These rings are cut transversely and are compressed when in place. In the case of the broad ring, a junk ring is fitted, secured by the pump-rod nut; the narrow rings are commonly sprung over the plunger into the recesses provided.

The spare gear should be kept up to the establishment, since it is frequently required.

The old pattern Admiralty pump is made in the following seven sizes:—

Description.	Diam. of Steam Cylinder.	Stroke.	Diameter of Pump.	Capacity in tons per hour.	Revs. per minute.
No. 1	9 ins.	9 ins.	6 ins.	70*	80
,, 1A	$7\frac{1}{2}$,,	9 ,,	5 ,,	48·5*	80
,, 2	$6\frac{3}{4}$,,	7 ,,	$4\frac{1}{2}$,,	31*	80
,, 2A	6 ,,	6 ,,	4 ,,	21*	80
,, 3	$4\frac{1}{2}$,,	5 ,,	3 ,,	10*	80
,, 4	$4\frac{3}{4}$,,	3 ,,	4 ,, Diam. of plunger $2\frac{13}{16}$.	3·7 (estim.)	100
,, 4A	$4\frac{3}{4}$,,	3 ,,	Do. $2\frac{7}{8}$ ins., upper part of plunger 2 ins.	1·9 (estim.)	100

Duplex Pumps.—For the purpose of supplying feed-water the old Keyham pattern pump has been superseded by various forms of direct-acting pumps having no eccentrics or crank-shafts. The Belleville, Weir's, the Worthington and Mumford's pumps, illustrated, are examples of these types.

These pumps have given satisfaction. It is particularly easy to examine the head and foot valves, which are generally fitted directly under separate covers. There is no side thrust or bending moment on the pump-rods, and the glands therefore wear better and the leakage is slight.

In 1896 a pattern of pump was adopted by the Admiralty, having the crank-shaft situated below the pump casting; by this means a long connecting-rod is secured. The slide valves are worked

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* Efficiency estimated at 0·9.

[illegible] et, and the sectional f that of the barrel, he pump is designed r bilge and fire- rvice purposes.

[illegible]

Whenever a feed mp is started, the t cocks should be ft open for a few rokes, to get rid of r from the pockets f the passages.

The amount of lift llowed to the foot nd head valves hould be carefully djusted, otherwise he regularity and moothness of working of the pump may be prejudicially affected.

Weir's Feed Pump.*—The arrangement illustrated Fig. 60) is fitted in vessels whose engines un at a high speed nd where it is inadvisable to drive the pumps from the main ngines. The pumps re automatically controlled by the quantity of feed-water in he float tank. This type of pump is usually fitted in duplicate, each apparatus being capable f supplying all the [illegible] ull speed. The feed- [illegible] he float tank, placed

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* [illegible] Weir for the information

[illegible] sition lower than [illegible] nent is placed in [illegible] om the float tank [illegible] ps have gunmetal [illegible] ese-bronze rods. [illegible]

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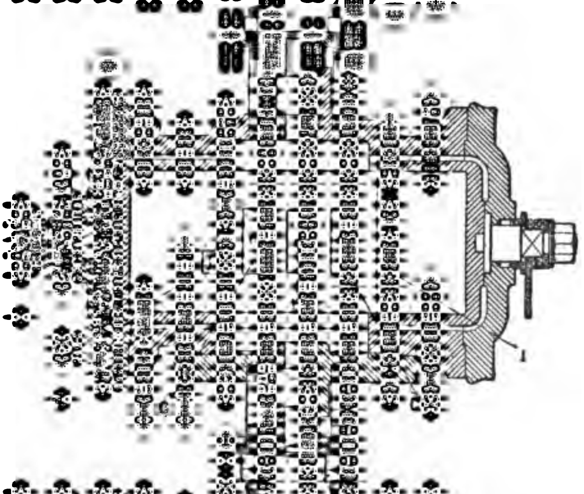

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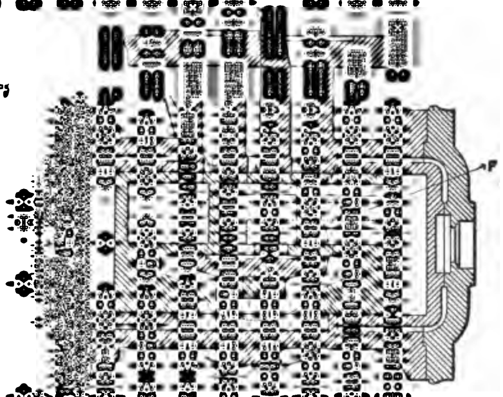

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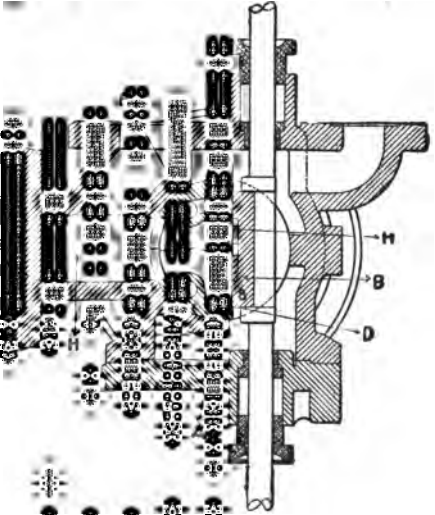

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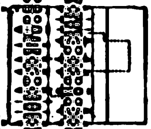

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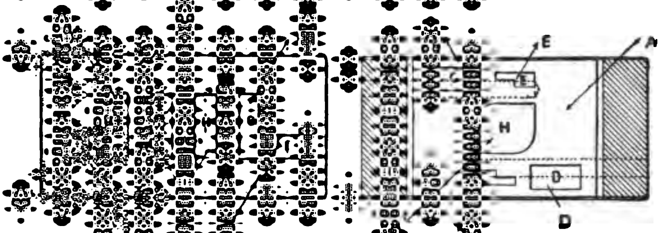

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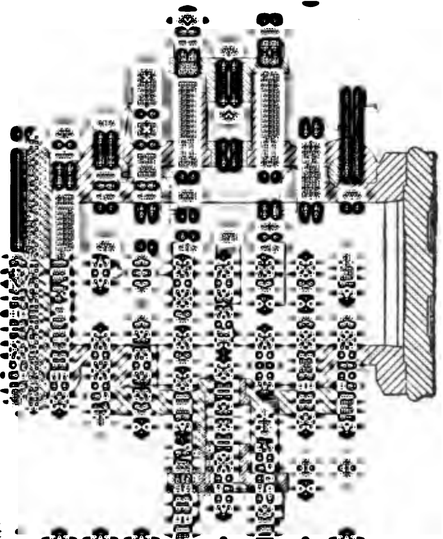

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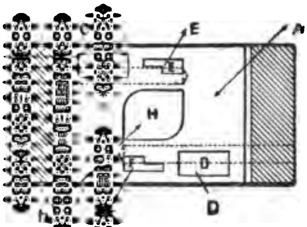

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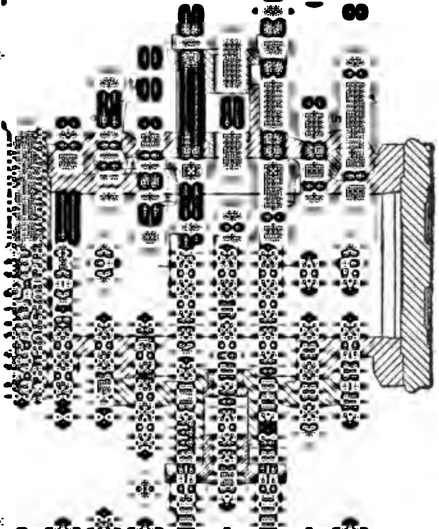

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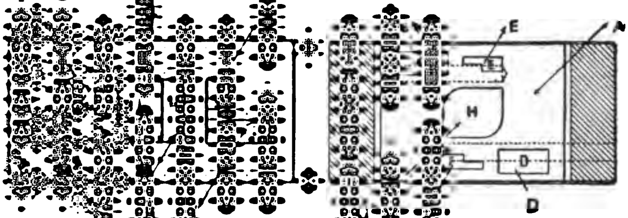

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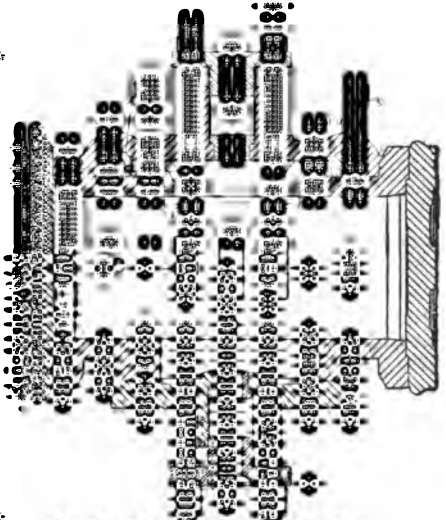

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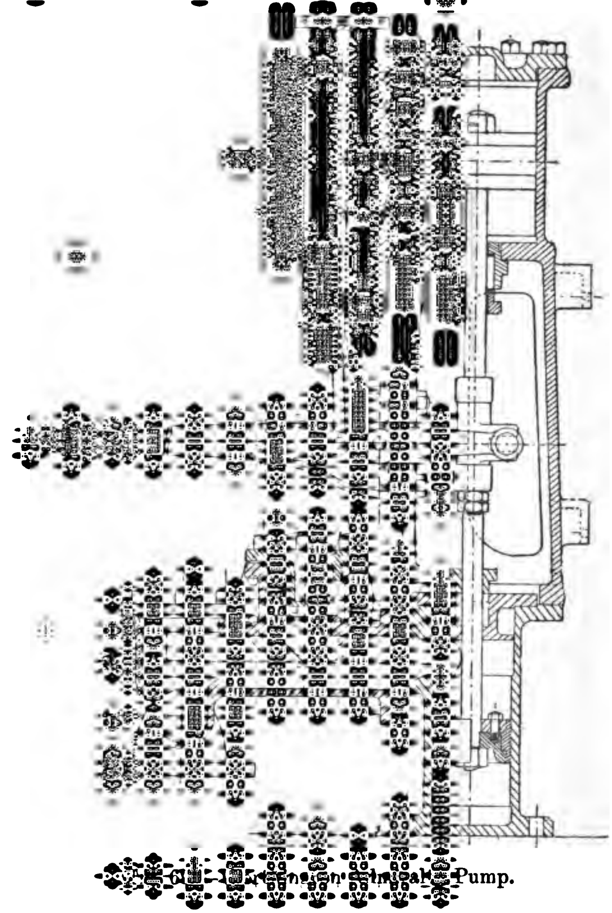

[illegible] Pump.

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to divide the lost motion equally, move the valve each way until it touches the nuts, and see that the port openings are equal. The most reliable way of setting the piston at half-stroke is to screw the gland up hard, so that it cannot move with the rod; then prise the rod up and down till the piston touches the cover and cylinder bottom respectively. Make a mark on the rod close up to the gland in each of the above positions. Divide the total distance between the marks by 2, and make a central mark, which is then brought up to the gland at half-stroke. If it is necessary to remove, or tighten up, the nuts on the piston-rods, the latter must be prevented from turning; otherwise the valve levers may be strained. When prising the piston-rods, apply the crowbar under the solid part of the crosshead, to avoid damaging the lugs.

Probable causes of irregularity:—

(1) The most usual cause is a leaky or throttled suction pipe, which produces hammering or a short stroke. The pipes should have easy bends, and if a strainer is used the net area of the holes in it should be about thrice that of the pipe.

(2) The slide-rods, being disconnected to repack the glands, may have been turned round, on reconnecting, so that the valve setting is altered.

(3) The stuffing-boxes may be too tightly packed. The turns of packing should be cut so that they do not quite butt before being screwed up in place.

The piston- and plunger-rods are screwed into a sleeve piece and are secured by cotters. This fastening may need tightening periodically.

Mumford's Duplex Pump.—The illustration (Plate V.) gives a sectional elevation through one cylinder and piston; a sectional plan, and a cross-section through both cylinders and pistons. As will be seen, the cylinders are made long—more than twice the length of the stroke—and are fitted with long pistons, such that the ends do not pass the middle of the cylinder. These pistons are fitted with spring rings at each end. At one side of the bore of each cylinder, in the middle of its length, is an ordinary three-port valve face. The middle port is for the exhaust steam which is led into a common pipe at the side of, or underneath, the cylinders. The other two ports are for steam, and are led to the two ends of the adjacent cylinder, as shown by the dotted lines in the plan (Plate V.). Each end of each piston on one side is made in the shape of an ordinary D slide valve, and these slide valves are so placed that, when the pistons are set true with the valve faces in the cylinders, and guided so as always to travel without turning, the slide valve at one end of the piston admits steam to one of the ports in its valve face and opens the other port to exhaust. Alternately, the slide valve at the other end of the piston opens the other port to steam and the first one to exhaust. Thus each piston, in making its stroke, alternately opens the end of the adjacent cylinder to steam and exhaust, and acts as a slide valve to it. The steam cannot pass to either end of either cylinder, except through the slide valves in the pistons, in the manner described above.

The arrows in the figures show the direction of the steam in the position illustrated.

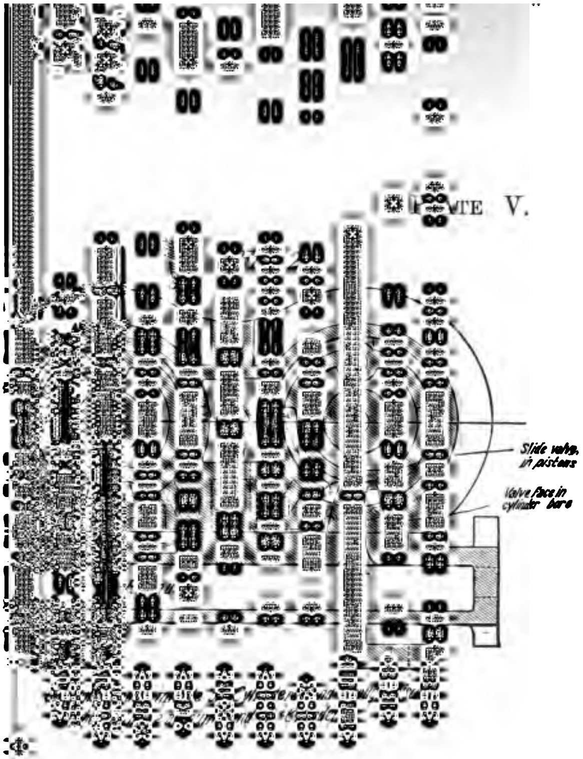
The steam ports are taken into the cylinders at a little distance from their ends in order to provide cushioning for the pistons; a certain quantity of exhaust steam is thus shut in the cylinder at the end of each stroke. There is a small supplementary steam port, passing from the end of the main port to the extreme end of the cylinder, whose function is to admit steam at the beginning of the strokes. When the main port in the slide face is covered, the exhaust steam is prevented from escaping through these supplementary ports, by the small non-return valves fitted to them.

In Fig. 2 the slide valves at one end of the piston are shown in full lines, and in dotted lines for the other end. There are small starting ports in the middle of the length of the cylinders and pistons, not shown in the figures. If the pump happens to stop with both pistons near the middle of the stroke these starting ports are brought into use; they are essential in such a case, because either piston can travel a certain distance about the middle of its stroke without affecting the steam distribution.

Upkeep.—The cylinders and pistons must be kept well oiled; wipers should be attached to the rods. The pistons are removed for inspection by taking off both cylinder and pump covers; the steam pistons are then pushed home to the stuffing-box end; the nuts of the plunger rods are taken off, and the pins and clutches on the rods are driven out. The pistons and rods can now be drawn right out of the cylinders. When the pistons are replaced they must be entered carefully on the guide studs fixed to the front covers.

The Belleville Feed Pump.—This pump is of the direct-acting type; the slide valve is worked by means of the tappet gear shown in Fig. 70. The pump is intended to suit its speed to the amount of opening of the self-acting feed valve on the

PLATE V.



[illegible] STEAM CYLINDER AND PISTON OF MUMFORD
[illegible] PUMP.

boiler; when the latter is entirely closed the amount of leakage past the water piston is sufficient to allow of a slow movement of the pump. At such times the effort of moving the slide gear might be sufficient to stop the pump at the end of its stroke, but relief is afforded by tappet valves, which connect the pump cylinder to the suction side, when knocked open by the piston just before the slide gear is engaged.

The travel of the slide valve increases with the piston speed—that is, with the violence of the blow given by the tappets. To prevent racing, the slide face is bevelled at its ends, so that, when the travel of the slide valve exceeds a certain limit, steam is admitted to both sides of the piston at the same time.

A condensing ejector is fitted, which uses the exhaust steam from the pump to warm the water supplied thereto. A starting or priming injector is used to fill the suction pipe and pump chambers when the feed tanks are below the level of the pump.

On Starting.—All the feed pumps should be warmed and moved as soon as there is sufficient steam for the purpose. One pump in each boiler-room should be started before the stop valves on the boilers are opened out.

The operations for starting a pump are:—

(1) Connect the pumps to the feed tank.

(2) Charge the suction pipe and pump by means of the priming injector.

(3) Open the steam valve full bore and turn the exhaust steam into the auxiliary exhaust pipe.

(4) Warm the steam cylinder by moving the slide lever.

(5) Shut off the priming injector when the pump is working regularly.

(6) Open the delivery valve very gradually; while the ship is manœuvring, the amount of opening should be only moderate.

When the main engines have been adjusted at the required speed:—

(1) Open the delivery valve full bore.

(2) Turn the exhaust steam into the condensing ejector and adjust the steam valve of the latter; an excessive amount of opening causes hammering. The condensing ejector is only used when the main engines are running steadily at sea.

If the pump becomes too hot for the hand to remain upon it, the priming injector should be brought into use till the temperature is reduced.

On Stopping.—Reduce the amount of opening of the delivery valve, and turn the exhaust steam from the condensing ejector into the auxiliary exhaust pipe.

Whenever the consumption of steam by the main engines is reduced or stopped, the Belleville feed arrangements tend to run up the level of the water in the boilers; hence the delivery valve must be regulated on such occasions.

Irregularities.—Racing may occur, on account of one or any of the following causes:—

(*a*) Shortness of water in the feed tanks.

(*b*) Excessive temperature of the feed-water supply.

(*c*) Sudden drop of pressure in the delivery pipe, such as occurs when all the self-acting feed valves open simultaneously on the main engines being stopped.

If the pumps race they are stopped automatically by the excessive travel given to the slide valves, which opens both ports to steam.

To re-start the pumps under the circumstances given above:—

(*a*) Shut the delivery valve and fill the tanks.

(*b*) Use the priming injector, and, as a further resource, apply a jet of water directed from a hose on to the outside of the pump barrel to cool it.

(*c*) Move the slide valve by hand and open the delivery valve gradually.

A sudden acceleration at the beginning of each stroke may be due, either to an obstruction in the suction passages, the presence of air in the pump, or to the temperature of the feed-water being excessive.

Sluggishness at the end of each stroke indicates an obstruction in the relief nipples, or a deformation of their tappets, or excessive wear of the slide-valve working surfaces.

If the speed is out of proportion to the delivery of the pump, the cause may be leaky valves or water pistons, in which case the pump works too freely when the delivery valve is shut.

A deficiency in the speed of working may be due to wear of the slide gear or working surfaces of the slide valve.

Adjustments.—The pumps must be thoroughly drained when idle. The tanks, strainers, and condensing ejectors must be periodically cleared of scale and obstructions.

To remove the pistons for examination, take off the cylinder covers, and, in the case of the pump piston, remove the tappet valve; ease the packing gland; remove the keep plate; ease the lock nut on the rod to be removed, and unscrew the rod; remove the lock nut and withdraw the piston.

The water pistons are packed with ebonite rings, which must be renewed as required; a brass band is used to compress the rings in place. The water pistons are sometimes made of solid ebonite discs with cover plates which, when refitted, must be removed and replaced one at a time.

FEED-WATER HEATERS.

The use of feed heaters is conducive to economy, and they are largely employed in the Merchant service. It is found also that they increase the life of a boiler, because the strains due to expansion and contraction are less when hotter feed-water is supplied.

The principle of the feed heater (Fig. 72) manufactured by Messrs. Weir and by Messrs. Worthington is as follows:—The exhaust steam from the auxiliary engines—or "live" steam as the case may be—enters an annular chamber through a valve, and then passes through a perforated plate into the heater. The feed-water from the hot well is forced by a pump through a valve and is sprayed into the heater. This spray thoroughly mixes with the steam entering through the perforated plate and absorbs the heat of the steam. The feed-water and condensed steam fall to the bottom of the heater and lift a float, which admits steam to a second pump. The latter forces the heated water into the boiler. The feed-water can thus be raised in temperature by a considerable amount. The automatic regulating gear is so arranged that there is no external gland to be packed, and consequently less danger of the valve sticking. The steam admission valve to the heater is of special construction. It closes automatically by gravity, and is fitted with a dash pot to prevent slamming. This valve prevents water from entering the supply pipe should the heater become filled with water.

As an example of the saving to be effected, suppose an engine of 10,000 I.H.P. to be using 15 lbs. of steam per H.P. hour. If the feed heater using exhaust steam raise the temperature of the feed-water from 120° to 210° F., the saving per hour will be 13,500,000 B.T.U. Then if 1 lb. of coal be valued at 11,000 B.T.U., the saving is 1230 lbs. of coal per hour.

The heater should always be placed at a considerable height above the pumps, and if it is desired to heat the feed-water as much as possible the height should not be less than 20 ft., in order to prevent the possibility of the pumps becoming filled with vapour.

Where exhaust steam is not available considerable economy is obtained by taking steam from the intermediate or low-pressure receivers, because although the work which would be done by the further expansion of such steam is lost, yet this loss is inconsiderable compared to the heat imparted to the feed-water by the condensation of the steam abstracted.

Surface-condensing Feed Heaters.—Feed heaters which resemble surface condensers in their construction and action are made by some engineers. The exhaust steam and the feed-water are not mixed, hence there is less risk of oil being carried to the boilers, because the condensed exhaust steam can be filtered after leaving the feed heater.

AUTOMATIC FEED-WATER REGULATORS.

These fittings have become important; they are especially useful in the case of a battery formed of numerous water-tube boilers as fitted in the stokeholds of some recent warships, and they have contributed to a more uniform distribution of feed-water than was obtainable by hand regulation alone.

There are at least two separate types of this apparatus :—

(*a*) The regulator may directly control the amount of water admitted to the boiler, and is therefore distributive in its action. One of the earliest examples of this kind was patented by Messrs. Thornycroft, and is described later, as is also the one designed by Messrs. Laird. The regulator used on the Belleville boiler is also of this type.

(*b*) The regulator may be fitted to control the supply of steam to the feed pump, and so adjusts the quantity of water delivered by the latter. If the pump supplies more than one boiler, the steam valve is actuated by a float placed in the feed tank, as in the arrangements fitted by Messrs. Weir, and other makers, in many merchant vessels. If each boiler is supplied by a separate pump the float is contained in the boiler, as in the arrangement known as Reed's and described later.

Attention Required.—Feed-water regulators should not be regarded as entirely automatic in their action. Experience shows that care and attention are required by them, and the working parts must be kept scrupulously clean. When in use the apparatus should be frequently examined, and tested by hand to ensure that it moves freely.

Thornycroft's Feed-water Regulator.—This apparatus consists of a vessel floating on the water in the boiler. The float is attached to one end of a lever, pivotted on an axis which can be raised or lowered from the outside of the boiler; to the other end of the lever a balance weight is fixed. A rod is attached to the lever at a point near the axis, and actuates a small double-beat valve, which regulates the quantity of water admitted to the boiler. This valve is contained in the boiler and cannot be tested by hand. The axis of the lever can be so adjusted as to maintain the water level in the boiler at a height which can be varied over a certain range.

Laird's Feed-water Regulator.—This apparatus is similar in principle to that of Messrs. Thornycroft, but the valve is of the piston type and is actuated by the float in such a manner as to increase or decrease the area of certain slots in the valve casing, through which the water flows into the boiler. The valve casing is mounted outside the boiler, and the valve spindle is prolonged through a gland, so that the freedom of the valve can be tested by hand. With this arrangement the water line is at a fixed level, and cannot be adjusted as in the Thornycroft pattern.

Mumford & Anthony's regulator is similar to Thornycroft's in principle. The float is fitted in a separate chamber communicating with the water and steam space of the boiler by levelling pipes. The valve motion is enclosed in the chamber, and an outside spindle and wheel are fitted to enable the water level to be adjusted.

Reed's patent automatic regulator (Fig. 71) consists of a rocking lever, to one end of which is attached a lead weight of about 4 lbs. The rocking lever is pivotted, in or about the centre of its length; and the float is attached to the other end of the lever. The lever actuates a steam valve, which regulates the supply of steam to the feed pump of the boiler in question. It will be seen that, when the water level rises in the boiler, the float will rise, and, by drawing the valve down, will reduce the supply of steam to the pump; on the other hand, if the water level is low the float will lift the counterbalance weight, and raise the steam valve so that more steam is supplied. The lower part of the equilibrium valve is made $\frac{1}{64}$ in. less in diameter than the upper seating. A small bye-pass, or direct supply, steam pipe of about $\frac{1}{2}$ in. in diameter is fitted to each pump to prevent it coming to rest. With this arrangement each boiler must be supplied with feed-water by a separate feed pump.

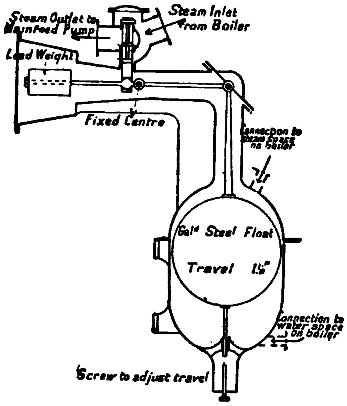
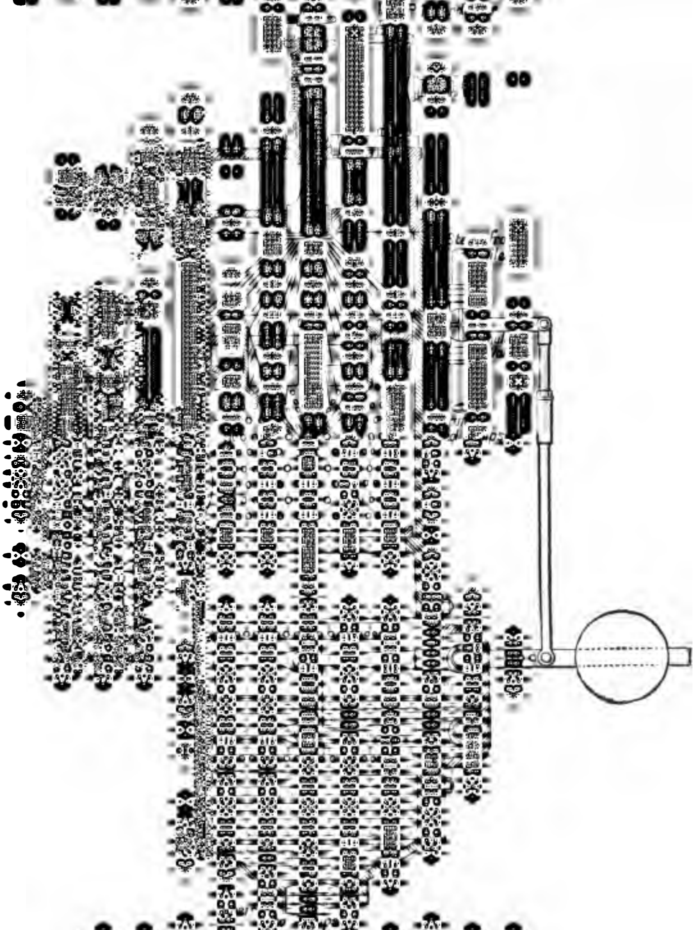

Steam Outlet to Mainfeed Pump
Steam Inlet from Boiler
Lead Weight
Fixed Centre
Connection to Steam Space on Boiler
Galᵈ Steel Float
Travel 1½"
Connection to Water Space on Boiler
Screw to adjust travel

Fig. 71.—Reed's Regulator.

Weir's Feed Heater and Automatic Regulating Gear.—This apparatus is shown in section (Fig. 72). The feed heater is similar in its action to the common jet condenser. The cold feed-water passes through the spring-loaded valve on the cover [illegible] eated by contact [illegible] ylinder exhaust,



[illegible] Automatic [illegible]

[illegible] of the apparatus. [illegible] perforations, are [illegible] mly. The water falls to the bottom of the heater, in which is placed a round galvanised iron float, with watertight bottom and sides, but open on the top.

This float is suspended on two levers, so as to move up and down with a parallel motion; the top lever axle is carried through the door at one end, and is balanced by a lever and weight. The float is always full of water, and the weight is adjusted to balance when one-half is immersed in the water. To the weight lever another lever is attached, which actuates the throttle valve and controls the supply of steam to the feed pumps. When the water in the heater rises, the float is raised, and the throttle valve opened; and when the water level is lowered the float follows, and the valve is closed. The level of the water is thus kept constant in the heater, and the pumps are completely filled with water.

The lead of the steam is so arranged that the pressure tends to keep the regulating cock tight, although it may have worn slack in its shell. The cock is fitted with a parallel key, the shoulder of which is pressed against the bottom of the stuffing-box and tends to keep the gland slack.

The feed heater should be opened out and cleaned about once a twelvemonth.

The regulating cock should be opened out and the parts washed with paraffin about once a month, when first fitted and until the pipes become cleared.

The float in the heater must always work quite freely; it is designed to balance the weight on the lever, when full of water and immersed one-half. On the easy working of the float and regulating valve depends the regular automatic action of the pump.

Yarrow's Automatic Feed Apparatus.—This system is free from all moving parts. The feed water is supplied to a boiler by means of a pump specially allotted to that boiler. The steam for working the pump is not taken, as usual, from the upper part of the boiler, but from near the water level. When the water level rises, instead of steam passing into the cylinder of the feed pump, water passes into it and materially reduces the speed of the pump. When, on the other hand, the water level falls, team passes to the cylinder of the pump, and the latter starts work more rapidly, until the proper water level is reached. There is a means of raising and lowering the open end of the pipe taking steam to the pump, which can thus be adjusted with respect to the water level. This apparatus has been fitted in some destroyers built by Messrs. Yarrow for foreign powers.

CHAPTER XIII.

EVAPORATORS.

EVAPORATORS are fitted to supply the make-up fresh feed-water necessitated by the leakage of steam and water through the joints and glands of a condensing steam engine. In H.M. Navy they are also used to supply the distilling condensers which replenish the drinking water tanks; in passenger ships a sufficient quantity of drinking water is generally stored, so that the evaporators are not required for that purpose.

An evaporator may be described as a boiler heated by steam coils; its principal requirement is that the scale deposited from the salt water feed may be easily removed. This scale is deposited on the shell of the evaporator and on the steam heating coils; the latter should be so shaped that most of the scale may be cracked off by the change of shape, caused by the contraction and subsequent expansion of the coils, which occurs when the evaporator is blown out.

The operation of blowing out the evaporator should be carried out once in each watch, if the evaporator is in constant use, to ensure the continued efficiency of the heating surface. Experiments quoted by Mr. Morison * showed that the output of a certain evaporator, with volute steam coils, gradually decreased from 32 gallons to 4 gallons an hour in the course of forty-eight hours. At the end of this period the scale was cracked off by sudden expansion, when the output immediately rose to 17 gallons an hour. Further experiments gave a similar result. Mr. Morison estimates the loss of feed-water by leakage at about 8 tons per 1000 I.H.P. in twenty-four hours for a good passenger boat; and about 10 tons per 1000 I.H.P. in twenty-four hours for a cargo boat. The amount of leakage will vary with the care bestowed on the tightness of the joints and glands of the engine; and it is assumed that less attention can generally be bestowed in the case of the cargo boat. The committee appointed to report on naval boilers estimates the loss in H.M. vessels at about 6 tons per 1000 I.H.P. in the twenty-four hours, reckoned on the full power of the engines.

In addition to the above quantities, about 12 tons a day is required for the use of a battleship carrying a crew of 500 men.

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* *Liverpool Engineering Society*, and *Engineering*, April, 1895.

The principal points in the care and working of evaporators are:—

(1) To prevent priming. General experience shows that the water level should be rather below the upper surface of the steam coils, so that the bubbles of water thrown off the surface with the steam shall be evaporated by the upper exposed heating surface. The proper determination and regular maintenance of the water level are most essential.

(2) To supply sufficient feed-water so that the density may be kept down by continuous brining. The density of the water in the evaporator should be from 25° to 30°, reckoning sea water as 10°. If the supply of feed-water is insufficient, the amount of the brining must be checked to preserve the water level, and in such a case the density will be high, scale will rapidly accumulate and put the evaporator out of action. If, on the other hand, the brining is excessive the evaporator will require an extravagant expenditure of coal, on account of the amount of hot water discharged through the brine valve; the working density is then too low.

N.B.—Quantity of water to be blown out to maintain a certain density:—

Let n be the density as compared with that of sea water taken as unity.

Let x = quantity of water blown out of evaporator.
y = " " evaporated.

Then, assuming the density of the evaporator remains constant, and neglecting the salts deposited, we have

$$nx = x + y.$$

Thus if

$n = 1$, the water to be blown out must be equal to the water supplied.
$n = \frac{3}{2}$, " " " $\frac{2}{3}$ of the "
$n = 2$, " " " $\frac{1}{2}$ " "
$n = 3$, " " " $\frac{1}{3}$ " "

(3) On starting the evaporator the water made should not be discharged to the reserve tanks until it is ascertained to be fresh; this is best effected by frequently tasting the discharge from the distiller. The secondary steam valve should be opened out slowly on starting.

(4) Continuous brining is advisable; the density is thus kept low and constant and the amount of scale deposited is reduced, so that the interval, after which the evaporator must be opened out for cleaning, is lengthened. A convenient method of brining is by means of a small suction pipe led from the brine valve (which should be of the non-return type) to the bilge pump. A small quantity of dense water is thus withdrawn at every

stroke of the pump. If such a connection is not available, the brine is simply blown overboard through one of the numerous discharge valves in the engine-room; as the amount of opening required at the brine valve is very small when the discharge is continuous, it is necessary to clear it by occasionally opening the valve wide for a short time. The bottom blow-out should be led direct to the sea, to secure cold water for the purpose of cracking-off the scale by expansion and contraction.

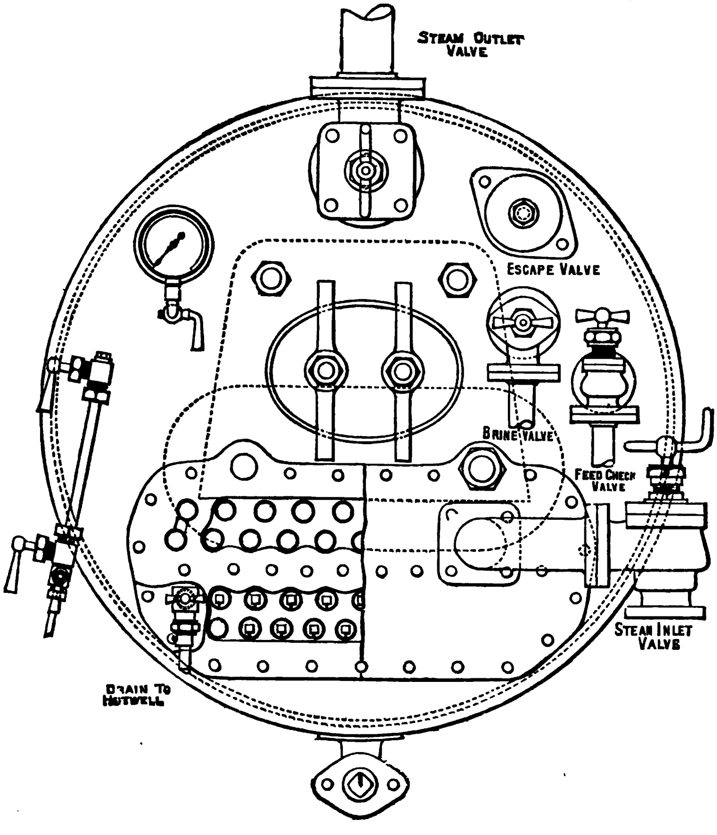


Fig. 73.—Weir's Evaporator (Old Type).

(5) The amount of steam supplied to the heating coils must be adjusted according to the amount of water evaporated, in

such a manner that the pressure of the secondary steam is constant. The best pressure to maintain depends on the particular

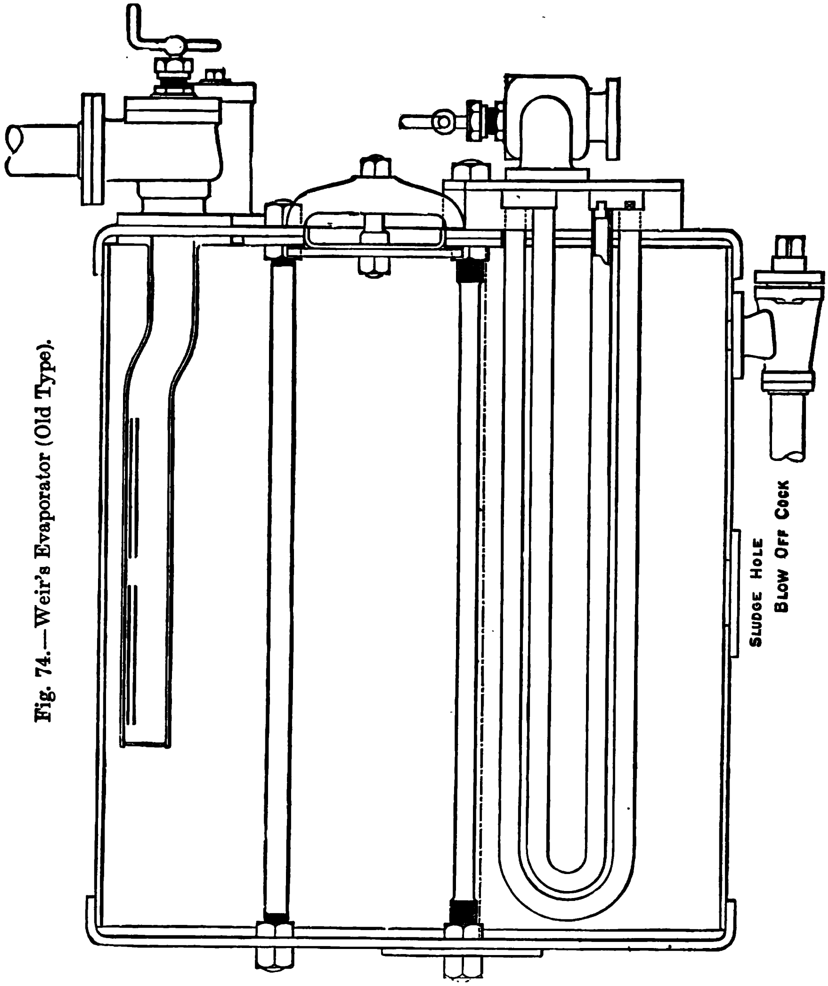


Fig. 74.—Weir's Evaporator (Old Type).

type of evaporator. The drain from the steam coil should discharge hot water only; the amount of opening must be determined by experience.

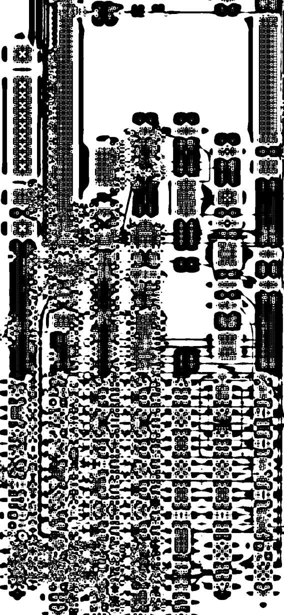
(6) The evaporator must be completely blown out at least once a watch to crack off the scale; it must be opened out and the coils removed for the purpose of chipping off and removing all scale after the evaporator has been in use for a certain period.

The method of blowing out is as follows:—Shut the outlet steam valve and open the bottom blow-out cock or valve. When the water is completely blown out, shut the inlet steam valve to the coils. The evaporator is then run up from the sea, through the blow-out valve, or pumped up, by means of the feed pump, to a level such that the steam coils are covered. In the latter case the blow-out valve is closed. When the water level is restored steam is again admitted to the coils, which are thus suddenly heated, and the scale upon them is caused to crack off. The water can then be blown down to the proper level and the various steam and brine valves can be adjusted to working conditions. The whole operation can be effected in from five to ten minutes.

The old type of **Weir's Evaporator,** of which there are many still doing good service, consists of a cylindrical steel shell, in which the heating surface is composed of a series of U-shaped, solid drawn copper tubes, expanded into a cast-iron tube plate jointed on the lower portion of the front of the shell. The tube plate and group of tubes are withdrawn together for cleaning purposes; sufficient space must be provided in front of the evaporator for this operation. If a manhole is provided in the back plate, opposite the end of the tubes, it will be found to greatly facilitate the operations of removing and replacing them. A manhole is generally provided in the front plate, and in cases when it is not convenient to withdraw the tubes for cleaning and chipping a large portion of the scale can be shaken off by means of a hammer inserted through the manhole and applied over as much of the length of the tubes as can be reached.

If the evaporator is blown down once a watch it will not be necessary to draw the tubes more than once a fortnight. It will be found very advantageous to carry a spare set of tubes for each evaporator, so that one set can be cleaned, at leisure, whilst the second group is in use.

The time required to change the tubes and clean out the evaporator is about six to eight hours. After the steam coil has been removed, all the loose scale should be removed from the bottom of the evaporator; the bottom blow-out valve, the brine cock, and the pipes attached should be removed, if possible, and thoroughly cleared of the scale which tends to accumulate and choke them. The coating deposited on the internal surfaces



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Weir's evaporators
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d at one end to a
et pocket, D, while
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pipes, E, by means
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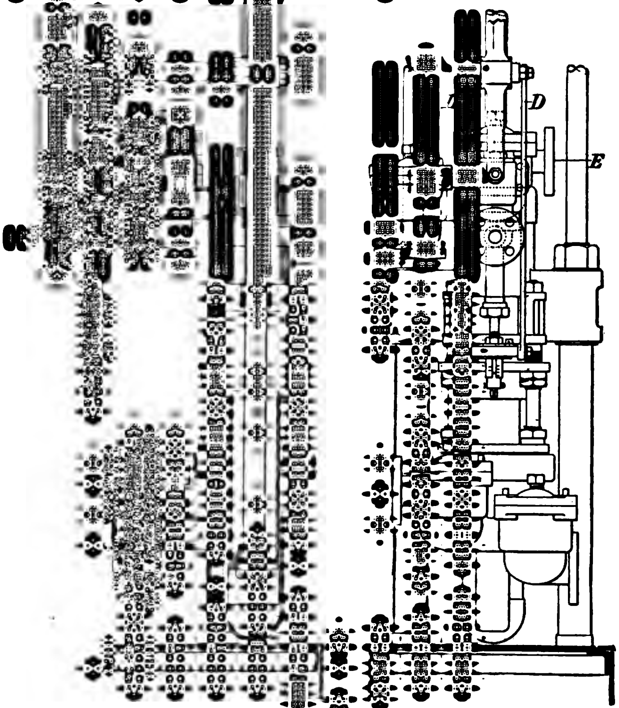
element, B, which has free ends whereby the condensed steam returns to the bottom end of the steam inlet and is drained to the condenser through the pipe, C, a solid web of metal being cast in the pocket to isolate the drain from the inlet steam. The gunmetal door is arranged to hinge back to permit the tube elements being withdrawn, as described on page 249. Immediately over the tubes are arranged the diaphragm, G, and the cowl, F, by which the steam is separated from any entrained water, thus preventing any priming. Any water carried up with the steam is returned to the generating chamber by the return pipe, H. The diaphragm is held in place by screw pins, and it is advisable to remove this every twelve months to note the condition of the steel dome.

Fig. 75 shows the most recent design of low-pressure evaporator, as fitted in the five battleships of the "King Edward VII." class and in the six cruisers of the "Antrim" class.

Description of Feeding and Brine Arrangements.—With evaporators using low-pressure steam in the coils and thus requiring to be worked with a vacuum in the shell, the main problem to solve is to secure a reliable automatic means of withdrawing the brine. With the old high-pressure type of evaporator, the steam pressure in the shell was always sufficient to blow the brine direct into the sea, but in the low-pressure type the brine requires to be pumped out. This problem Messrs. Weir have solved by the introduction of a combination feed and brine pump working in conjunction with a vessel for diluting and cooling the brine, together with an adjustable means for varying the brine density.

Automatic Feed and Brine Pump.—The steam end of this pump is similar to the usual "Weir" type of steam end. The water end, however, is distinctly different, and is shown in section on Fig. 76. As will be seen, the pump end embraces two separate and distinct simple plunger pumps, A and B, each having its own suction and discharge valves. The top end, A, forms the feed pump, the bottom end, B, the brine pump, and the feed pump is generally twice the capacity of the brine pump —*i.e.*, if there were no diluting water the feed pump would put in twice the quantity the brine pump would take out, and this proportion would exist irrespective of the speed of the pump. In the latest pattern, the gun-metal valves are mitre-faced, and are arranged in groups, in separate valve-boxes, to facilitate examination.

The automatic supply of diluting water is arranged as follows :—On the discharge side of the feed pump is fitted a valve, C, positively opened by the gear, D, which is driven from the [illegible] that the valve, C, [illegible] esired. The feed- [illegible] he pipe, E, to the [illegible] opens the cooling [illegible] the cooling and [illegible] ng less than that [illegible] refore discharged [illegible] o the cooler. An



[illegible] tio of the amount [illegible] points of opening [illegible]

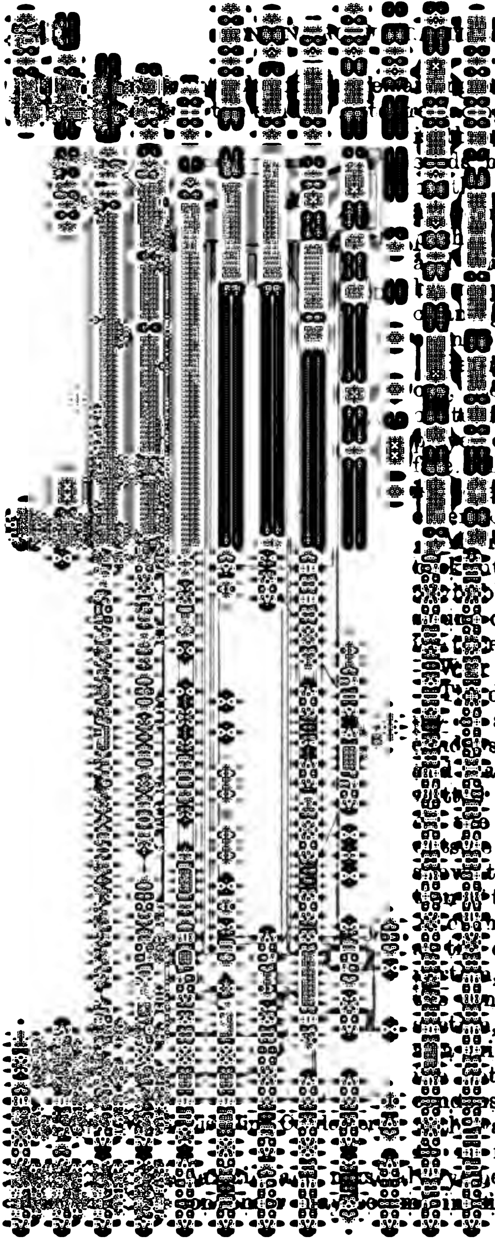
[illegible] d to the side of [illegible] ting water mixes [illegible] rine pump.

Instructions for Working Weir Low-pressure Evaporators.—Before starting the evaporator, see that the combination feed and brine pump is in good order, and that the brine index is correctly adjusted.

Then start the pump, and fill up the evaporator till the feed regulator puts a pressure on the discharge, as shown on the gauge. The proper working level is about 6 inches in the glass. Now open the coil drain valve the amount which has been found correct on the tests and on experience (nearly fully open). Next admit steam to the coils slowly, and allow the shell pressure to rise to about 2 lbs., then gradually open out the vapour outlet valve. Under ordinary conditions the production will be obtained with about 6 lbs. in the coils and 9 inches vacuum in the shell, or if no vacuum is obtainable, then 16 lbs. in the coils and 1 to 2 lbs. in the shell. The vacuum control valve is always adjusted so that the maximum vacuum obtainable in the shell will not exceed 15 inches. With these connections adjusted, the gear is in working order, and it is only necessary now to see that too much steam has not been turned on the pump, which will be shown by the sentinel valve on the discharge opening. Beyond this, the gear is quite automatic. The density should always be tried occasionally to see that the brine gear is in order, and that no leakage is taking place. If the evaporators are working continuously, they should be blown down every twelve hours; this operation is carried out as follows:—Shut the vapour outlet valve and allow the pressure to rise in the shell to about 12 lbs. Then quickly open blow-off to sea. When the water has been entirely blown out (which will be done rapidly), close the inlet steam valve. The cold feed entering from the pump will then condense the steam and hence create a vacuum in the shell, causing the sea water to be drawn in rapidly through the bottom blow-off. On the appearance of the water in the glass, the blow-off should be shut. Then set the inlet and outlet valves, and the gear will again be in working order. The expansion due to the sudden heating and cooling of the apparatus will loosen the scale formed.

In shutting off an evaporator, always close the outlet steam before the inlet. As the tubes become dirty, the openings of the inlet steam and coil drain valves will require to be slightly increased to maintain the production.

Instructions for Cleaning and Overhauling Weir Evaporators.—Take off all the nuts on the door, with the exception of one on the side opposite the hinges; leave this nut a few threads on the stud, next screw in the starting pins until the hinge pin is far enough back in the slot to permit of the smaller taper pins being



nt, and the door can
g the tubes, the door
guided on to the
y a small bar fixed
shell, the taper pins
oved, and the door is
into its place. Scale
t lying in the cham-
y be removed by the
g door on the bottom,
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to place, it is always
le, before the door is
on, to turn steam on
s and test the joints.

Distilling Condenser.

distiller consists sim-
an ordinary surface
ser placed vertically
ving the steam ad-
through the centre
upper tube plate
the tubes. Fig. 77
the general construc-
the gear, the portion,
e tube surface acting
condenser, while the
, B, acts as the cooler,
ndensed water pump
, C, being arranged
itable level to ensure
ttom portion of the
ser being always filled
ater. The air cock,
fitted between the
e kept slightly open,
cient through being

air-locked. The tubes are of solid drawn brass and are tinned on both sides, and then expanded into the tube plates. They are hydraulic tested, and the ends and tube plates re-tinned all over the surface of the tube plate. The packing gland, L, prevents any breakage being caused by expansion, and only in the case of a defective tube should the distiller require overhauling. In fact, the spare set of distiller tubes should rarely require to be used, as, if a few tubes give out from any cause, they may be plugged without causing any serious drop in the efficiency of the machine. Any description of soft packing is suitable for the stuffing-box ends. Care must be taken in rejointing the cover plates, M and M_1, that the joint is properly cut and properly in its place. Care must also be taken that when steam is turned on to the condenser it is done gradually, as a sudden opening of the steam inlet valve will cause water to be blown out at the top of the overflow pipe, H, and thus cause inconvenience. A small test cock, K, is generally fitted for testing the temperature and quality of the water produced by the distiller.

Caird & Rayner's Evaporator (Fig. 78).—In this arrangement the steam coils are of helical form, which gives them great elasticity; when subjected to variations of temperature and pressure they alter their shape in the same manner as the tube of a Bourdon gauge. This action causes most of the scale deposited on the coils to be thrown off, and secures a more continued efficiency of the evaporator. The tubes are secured to the steam chest by coned nipples and union nuts. The door, to which all the coils are attached, is easily removed, its weight being carried by means of a strongback fitted on the top cover. The steam joint for the door is a comparatively small one, so that the operation of removing the tubes and cleaning out the shell is much simplified; the necessary time required varies from four hours to one hour, according to the size of the evaporator.

The evaporator should be completely blown out once a watch, when in use.

In order to reduce the necessary heat of evaporation, this arrangement is designed to work at a vacuum of about 5 to 15 inches. The brine water must then be withdrawn by means of a suction pipe led to a convenient pump. It may be found that this evaporator has a tendency to prime when worked at a low vacuum; at a pressure of 5 lbs. above the atmosphere it is absolutely reliable and requires very little attention. The proper working level for the water is at the top of the heating surface; before starting, it should be run several inches lower to allow for an automatic rise, which tends to produce priming.

compression; but the necessary fittings for water injection are provided.

Compressors of this pattern have been supplied to all classes of modern vessels in H.M. Navy.

Instructions for Testing (see Fig. 89).—Remove the non-return valve and relief valve on the air outlet, and connect to the water-testing pump. Gag the relief valves on first, second, and third intercoolers. Open the drain cock on the first intercooler. Remove valve A, one valve B, valves C, D, E, and F, and their covers, also valve H. Remove the crosshead; the thrust of the plungers is then taken by the pump itself, and not by the working parts of the engine.

(1) Pump to 4000 lbs. per square inch, testing the fourth cooling coil, high-pressure barrel and plunger, and valve G. *N.B.*—The high-pressure ram will be forced in.

(2) Release the pressure, remove the valve G. Insert valve E. Pump to 2500 lbs. per square inch, testing the third cooler coil, high-pressure cover, and valve E. *N.B.*—The high-pressure ram will be forced out.

(3) Release the pressure, remove the valve E. Insert valve C. Pump to 1000 lbs. per square inch, testing the second cooler coil, low-pressure barrel and plunger, and valve C. *N.B.*—The low-pressure ram will be forced out.

(4) Release the pressure, remove the valve C. Insert valve B. Pump to 500 lbs. per square inch, testing the first cooler coil, connecting pipes, and valves B.

(5) Release the pressure, remove one valve B. Insert valve A. Pump to 150 lbs. per square inch, testing the low-pressure cover and valve A.

Packings.—Leather packings, cut from flat sheets and not pressed or moulded, are used. The flat sheet should be pared and planished to the required thickness; it should then be nailed on a wooden block, which is placed in a lathe, and the disc cut out by a knife tool to the bronze template provided. The high-pressure plunger leathers are soaked in warm water for a few minutes to render them pliable; they are then placed on a cone tool, whence they are transferred over the plunger head, and are closed into their proper grooves by a sleeve tool.

To Draw the Large Plunger for Examination.—Remove the top cover, unscrew the nut of the connecting link under the crosshead, put the engine on the top centre, screw eyebolts in the plunger top, and lift with tackle.

To Draw the Small Plungers.—Unscrew the high-pressure cover and the nut at the bottom of the plunger stem; put the engine on the top centre, and lift the plunger out by hand.

and contraction are not so great as occurs in spiral coils, and more attention is required to get rid of the scale. The steam joint, which has to be broken to obtain access to the heating tubes, is large and requires care to make it tight. An automatic float is fitted to regulate the feed supply. If it is found difficult to keep the density of the evaporator low enough, the feed-pump plunger and valves should be overhauled; if the difficulty continues, the opening under the float box should be enlarged, or an additional supply should be furnished to the feed pump from any convenient source.

Steam Connections.—The primary steam supplied to the heating coils of an evaporator may be led from the main steam pipe, or from a main cylinder receiver, according to the designed pressure and to the need of securing economy of coal. The secondary steam may be led to the low-pressure receiver of a compound engine when the additional water is only required for make-up feed; or, as an alternative, it may be led direct to the main or auxiliary condenser, as is usual in H.M. vessels. The secondary steam should not be led to the auxiliary exhaust pipe, the pressure in which varies considerably, especially in small vessels of high power; the variation of pressure causes irregular evaporation and may produce priming; moreover, the pressure is frequently so considerable as to exceed the load on the safety valves of the evaporator. In some new vessels the evaporator coils are supplied with steam from the auxiliary exhaust pipe, the evaporator being worked at a low pressure. If the water made is required for drinking purposes, the secondary steam is condensed and filtered before passing to the proper tanks. The condensers fitted for this latter purpose are cooled by sea water, which should be supplied in sufficient quantity, the temperature of the discharge being adjusted at about 100° F. A slight scale is formed on the tubes of these condensers, which should therefore be opened out and cleaned about once in six months.

Evaporators are sometimes arranged for *double effect;* that is, the secondary steam discharged by one serves as the primary steam in the heating coils of the other. The drain water from the first is discharged to the feed tank or auxiliary condenser, whilst that from the second can be passed through the filter to the drinking tanks. The object of this arrangement is to obtain the maximum amount of water per lb. of coal used, rather than per lb. of the weight of the distilling plant; as much as 20 lbs. of gained water can be obtained per lb. of coal.

N.B.—The precautions taken to prevent corrosion in boilers, whilst out of use, may be usefully applied for the preservation of evaporators made of steel plates.

CHAPTER XIV.

STEAM-BOATS.

Machinery of Steam-boats.*—The engines of the steam-boats carried by a ship are usually of the vertical, inverted-cylinder, direct-acting type, and are compound, with two cylinders. The larger boats have a tubular condenser, the smaller an outside copper pipe which, being immersed in the sea water, serves the same purpose.

These engines, being in all respects similar in design to the propelling engines of the ship, require the same care for their upkeep and management under way (see Art. 695, *et seq.*, *Steam Manual*). Very little oil is used for internal lubrication, and then at high speeds only; mineral oil alone is used for this purpose.

The air pumps require a frequent overhaul to clean the valves and chambers from greasy matter. The adjustments of the engines should not be left to the leading stoker of the boat, but should be carried out by a skilled mechanic under the engineer's direction; on all such occasions the piston clearances should be ascertained. When not in use the engines must be frequently oiled; they should be turned every day to prevent them rusting. A cover should be provided to protect them from the weather.

The boilers are generally of either cylindrical, locomotive, or water-tube type.

The water-tube type is specially suitable for steam-boats on account of the ease with which quick changes in the rate of steaming can be made, and also because of the short time needed to raise steam. The commonest minor defects developed in the water-tube boilers consist of:—(1) Buckling and burning of the casings, which are made of very light plating, lined with asbestos meal or millboard; (2) crumbling of the brickwork of the furnaces—this brickwork, on breaking away, exposes the casing plates to the flames. It is essential that the feed-water should be as pure as possible; any salt, grease, or other impurities in the feed-water are liable to choke the tubes and cause overheating and burning of the tubes. There is always a tendency to corrosion in the upper and lower drums, which must be checked by zinc and proper methods of preservation. External corrosion of the tubes at the junction with the lower tube plate may result from an accumulation of damp soot; this part being rather difficult of access, special means should be devised to remove all deposits.

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* See Arts. 491 to 494 and 695 to 697, *S.M.*

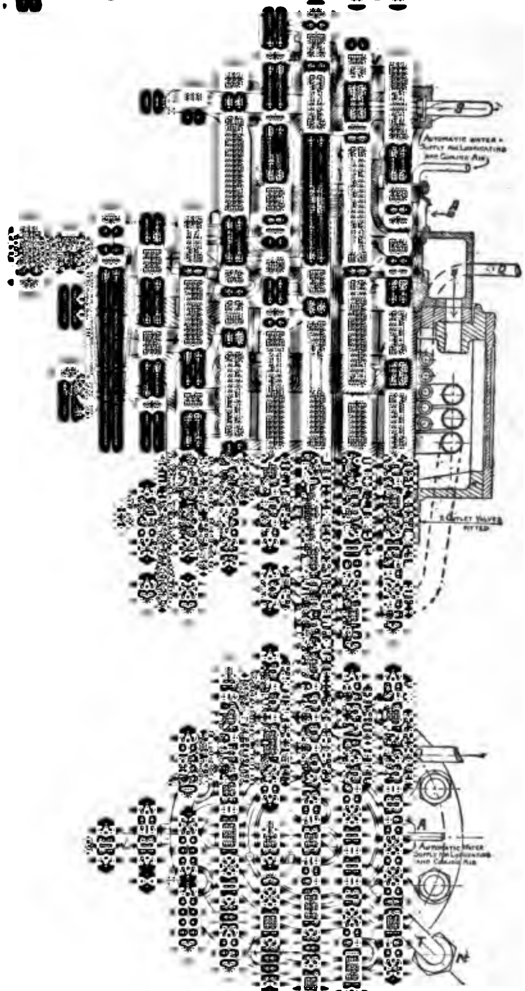
Cylindrical boilers are liable to external corrosion of the bottom plates, due to the action of bilge-water and the copper lining of the bilges. If the tubes are leaky the tube plates will suffer, particularly the back tube plate. If the boiler is allowed to run short of water, the crowns of the fire-box will be found buckled. This defect is often met with.

Locomotive boilers, in addition to the above-mentioned defects, are liable to damage at the foundation of the fire-box; the water spaces at this part are very cramped and difficult to clean, and an accumulation of greasy deposit may cause the stayheads to be burnt off and the plate to be cracked between the stay-holes, or the corner joints of the foundation rings may be cracked and leaky. The Admiralty direct (Art. 696, *S.M.*) that great care should be taken to prevent an accumulation of deposit in the boilers, and disinfecting powder is to be used at intervals. The boiler is to be filled to working height, and 1 lb. of disinfecting powder to every 2 or 3 gallons of water contained is to be added. The boiler is to be kept simmering from four to six hours and then blown out at 5 lbs. pressure. When cold, the boiler is to be washed out with a powerful jet of water.

Air Supply.—The boiler is run under a system of forced draught, the air being supplied to the closed stokehold by an independent fan in the larger boats, or to a closed ashpit by a fan driven by a belt from the main engines in the smaller steam pinnaces and cutters; in the latter case a damper is fitted in the air pipe from the fan, which is closed when it is necessary to open the furnace door.

The feed check valves on the boiler are liable to stick on their seatings; should this occur, cold water should be thrown over the valve box, and the latter should be tapped with a hammer.

The main feed pumps are driven by the main engines; if they do not act well, the feed tank will overflow and betray them. An auxiliary feed pump is fitted independently of the main [illegible] ated by means of a


Automatic Water Supply for Lubricating and Cooling Air
Outlet Valves Fitted
Automatic Water Supply for Lubricating and Cooling Air
A
N

[illegible] Air Compressor (Two-stage Type, 1897).

[illegible] may be either single, double, or triple. The single compressor is designed to pump up a reservoir, containing 10 cubic feet of air, to a pressure of 1700 lbs. per sq. in. in seventy minutes, and the double and triple compressors a proportionately greater amount.

Instructions for Care and Maintenance.—To disconnect, open the separator drain, and shut the air-outlet valves; shut the circulating water suction and delivery cocks, and open the drain cock on the tank. Unscrew the union nuts, S and T, and swing the pipe bends clear. Place the engine on the bottom centre, slack back the set screw, V, on the connecting nut, Y, and unscrew the nut. Take off the four nuts from the pump-barrel studs, and unscrew the stuffing-box, E. The top of the pump can now be removed and the high-pressure leather be examined or replaced; the pump-rod can also be withdrawn by hand and the leather, O, examined. The inlet valve, O, is examined by unscrewing the nut, F. All valve nuts are secured by set screws, and care must be taken that they are removed and replaced. To examine the high-pressure inlet valve, G, disconnect the pipes, S and T; unscrew the connecting nut, H; lift off the high-pressure barrel; take off the cap nut, I, and take the nut off the valve, G, which can then be removed. The high-pressure discharge valve, P, can be examined by removing the cap nut, J. To examine the low-pressure discharge valve, L, disconnect the nuts on the pipe, M. Great care must be taken not to scratch the working surfaces, as any roughness causes rapid wear of the leathers.

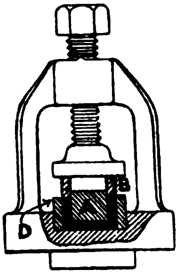


Fig. 92.—Press for Leathers.

After an examination see that all air joints are tightly screwed up, and turn the engine by hand to ensure that everything is clear before starting. This is especially necessary if any of the spare gear has been fitted, as all clearances are designedly small.

The packing in the glands must be kept soft and in good condition, to prevent the escape of air and fresh water.

Leathers, before being fitted, should be softened in lukewarm water. The discs are cut out of hide about $\frac{3}{16}$ in. thick. The flesh side of all leathers should be used as the working surface. Good hydraulic leather requires to be soaked several hours before being pressed in the moulds. As to cutting the leathers, see the notes under Hydraulic Machinery.

(All joints subject to air pressure are made with copper rings.)

To make the small plunger leather, first press the leather into the mould with the plug, A (Fig. 92); cut the edge off flush with the mould, D; place the ring, B, over the plug, A, and screw down, thereby pressing the leather into the corner of the mould, D. The leather hide should be planished and rolled before pressing it.

Instructions for Working.—Before starting, examine all fastenings and fill the lubricators. Open the separator drain and stop valves, circulating water cocks and the cylinder drain cocks. Immediately on starting the engine, pour fresh water into each of the pumps until it appears at the separator drain. The supply required to fill up when the columns are empty is about 4½ pints of water and two tablespoonsful of sperm oil, per pump; it is put in by removing the wire gauze. The small water-service valve should supply a stream about $\frac{3}{16}$ in. in diameter past the sight hole at A. Too much oil will cause a soap to be formed and will clog the valves.

The supply of circulating water should be regulated so as to keep the pipe, Q, at blood heat. The temperature of the pipe, S, will be much higher.

The action of the inlet valve is important in its effect on the efficiency of the pump; the clear beat of these, when working well, will be easily recognised after a little experience. Any defect in the leathers of the low-pressure piston, or in the valve facing, is made manifest by an excessive leakage of air on the downward stroke of the pump.

The efficiency of the leathers in the high-pressure plunger, and in the pump generally, can be tested by closing the outlet valve to the air reservoir, whereupon the pressure in the separator column should rise to 1400 lbs. in about 65 revolutions.

When the engine is stopped the separator drain must be opened immediately, otherwise the fresh water will be forced back into the pump and will cause considerable trouble on restarting.

Belliss Four-stage Air-compressor.—With the advent of higher pressures in connection with torpedo air service, the compressors now supplied (1905) are of the four-stage double-acting type, either steam- or electrically-driven, and fitted with the well-known system of forced lubrication to the engine and motion parts.

In the steam-driven sets the compressing pumps are placed above the steam cylinders of the engine, and worked directly from the prolongation of the piston-rods. In the electrically-driven sets the compressing pumps are driven direct by a suitable motor through a crank-shaft and connecting-rods.

The air is compressed in four stages up to a pressure of 2500 lbs. per square inch. The four-stage compression greatly increases the efficiency of the compressor, by reason of the more efficient cooling of the air during compression. The air passing through a set of cooling pipes between each stage, and the air cylinders and cooling pipes being surrounded by water, which is kept in constant circulation by the water pump, ensures thorough cooling of the air before it is discharged to the reservoir.

The action of the pumps will be readily understood by reference to Fig. 93.

The air is drawn in, on the downward stroke, from the under side of the low-pressure piston trunk, through the throttle plates, F, and past the inlet valve, P; the action of the inlet valve, P, being assisted by its own momentum at the turn of the stroke.

The first compression takes place above the piston and on the up stroke, the air being discharged past the valves, Q, through the first set of coils in the water-tank casing, R, where it is cooled before passing into the second compression cylinder through suitable valves, S.

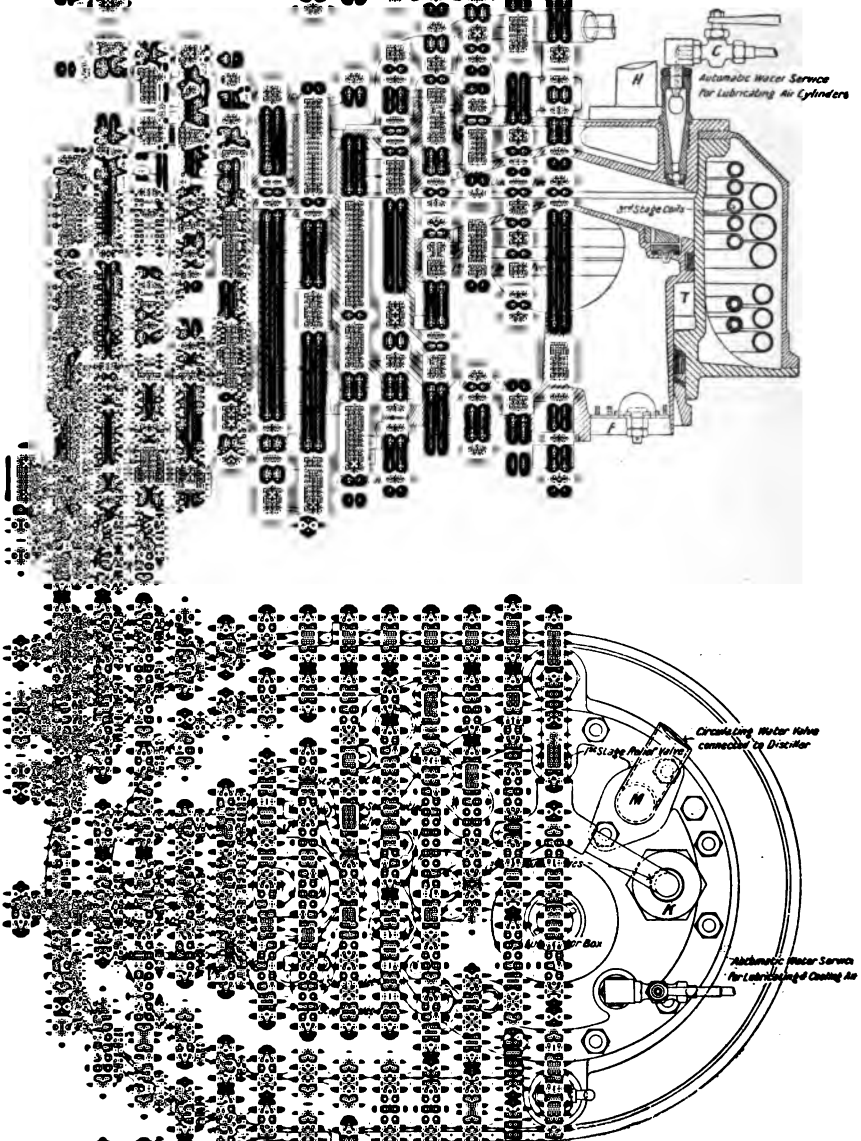
The second compression is effected on the return stroke, in the annular space formed by the trunk of the piston, T, the compressed air being discharged through a valve at U. It then passes through the second set of coils on its way to the third stage.

The third compression takes place on the top of the high-pressure piston, V, the air being sucked in on the downward stroke through a valve at V^1 and discharged on the return stroke through a non-return valve at V^2.

After passing through a third set of coils, the air enters the final compression chamber through a suitable inlet valve at W, and the compressed air is discharged past the outlet valve at X into the final set of coils in the tank, thence through the pipe, Y, and onward to the separator column.

Whilst passing through the separator column, the oil and water which has been fed into the pump for the purposes of lubrication is separated from the air and automatically drained away; thus the air is delivered to the reservoirs in a dry condition.

This automatic drainage is effected by means of a balanced float in the separator column. The air and water, on entering the column, are made to impinge against the inside walls of the float, thus effectively clearing the air of oil and water, which collects in the bottom of the float, causing it to sink and


C
H
Automatic Water Service for Lubricating Air Cylinders
3rd Stage Coils
T
F
Circulating Water Valve connected to Distiller
1st Stage Relief Valve
M
K
Automatic Water Service for Lubricating & Cooling Air

[illegible] Compressor (made by Belliss & Morcom, 1905).

operate a rotary valve. This valve opens the passage-way for draining purposes.

The high-pressure air, acting on the surface of the oil and water, forces it up through a pipe, which is in communication with the bottom of the float and the chamber containing the rotary valve, thence through the passage-way opened by the valve, and away to waste. When the water has been thus drained away the float rises, closing the passage-way and preventing escape of air.

A distiller is fitted to the steam-driven sets, which automatically gives a supply of pure distilled water. The stopcock, C, is for regulating the supply of distilled water to the pump.

A small quantity of oil is fed into the pumps along with the water supply, oil having a beneficial effect on the leathers and packing. A sight-feed oil-box, D, is fitted for this purpose.

In this four-stage type of compressor the circulating water does not come in contact with the working faces of the air cylinders, as in the two-stage pattern. The circulating-water pump is shown at Z. The water is lifted into and forced round the tank casing, through the pipe, G, into the top of the low-pressure cover, out at the pipe, H, and thence to the distiller. After circulating round the distiller coils it is discharged overboard or to the main drains.

Instructions for Care and Maintenance—Before Starting.—Examine all fastenings and fill lubricators. Open separator-drain and stop valves, circulating-water cock and cylinder-drain cocks. Blow through to warm steam cylinders. Give careful attention to the packing of the piston-rod glands to prevent the rods getting scored.

If the engine is of the enclosed type, drain off any water which may have accumulated in the crank chamber. See that there is a sufficient quantity of oil in this chamber, and that it covers the strainer. The oil strainer should be cleaned. It is of importance that the oil should be kept clean and free from grit, and occasionally it should be run out of the crank chamber and filtered. *Use Service Mineral Oil only.*

Fig. 93.

PISTON CLEARANCES.

Top, ...	= $\frac{1}{32}$ inch.	Bottom, . . .	= $\frac{1}{16}$ inch.

LIFT OF VALVES.

1st Stage—	Inlet, . .	$\frac{1}{16}$ inch.	3rd Stage—	Inlet, . .	$\frac{1}{16}$ inch.
,,	Outlet, .	$\frac{3}{32}$,,	,,	Outlet, .	$\frac{1}{16}$,,
2nd Stage—	Inlet, . .	$\frac{3}{32}$,,	4th Stage—	Inlet, . .	$\frac{1}{16}$,,
,,	Outlet, .	$\frac{1}{16}$,,	,,	Outlet, .	$\frac{1}{32}$,,

Starting.—*See that the circulating-water cock is full open, and test whether the pump is supplying water by opening the air cock,* A. The supply should be sufficient to keep the fourth-stage outlet pipe, Y, quite cool.

Regulate the *automatic water supply* for lubricating the air cylinders by opening the stop cock to distiller. The pet cock, O, is for further regulating the supply, and should allow of a stream of distilled water of about $\frac{1}{16}$ inch diameter passing the sight hole of the fitting. The water supply requires to be greased by a supply of oil from the lubricator box, D. The number of drops per minute should not exceed fifteen, and can be regulated by the thumb-screw, E. Only oil free from acid should be used; sperm oil is to be preferred. Too much oil will cause a soap to be formed, and will clog the valves of the separator column. See that the throttle plates, F, on the air inlet are closed and locked in position to deaden the noise made by the beat of the inlet valve. *See that the glands of the high-pressure and low-pressure air stuffing-boxes are screwed up tightly and evenly* to prevent the escape of air and fresh water.

Working.—On starting the pump, the automatic separator drain will not come into operation until sufficient water is collected to sink the float and work the valve. Then a constant discharge will be maintained at the nozzle. The separator-drain valve should be opened occasionally as a test of the satisfactory working of the drain, but the water discharged should be a negligible quantity. If the quantity is large, the valve must have become clogged, due to too much oil being fed into the pump. Moving the handle (on the separator-column side) backwards and forwards will free the float and clear the valve. This handle should only be used when necessary, and, when not in use, it should hang vertically downwards.

The action of the air inlet valve, P, is important in its effect on the efficiency of the pump. The clear beat of this when working well will be easily recognised after the necessary experience, and any defect in the valve facing can be seen or felt by excessive leakage of air on the upward stroke of the pump. If there should be any leakage past the air pistons, or if the valves or valve seats are at all damaged, warning will be at once given by the blowing of the relief valves.

The leathers used throughout the pump must be kept soft and in good condition, to prevent the escape of air and water.

Disconnecting.—Shut air outlet valves, and open separator drain. Shut circulating-water (suction and delivery) cocks, and open tank drain. Disconnect pipes, G and H. Unscrew union nuts, J, K, and L, and swing pipe bends to clear. Unscrew high-pressure barrel cap. Take off nuts from low-pressure cover studs and use forcing-off screws, O, for removing cover. Slack back set screws, M, on connecting nuts, N, and unscrew nuts. Pistons can now be readily removed by means of lifting eyes supplied.

All valves can be readily examined by screwing back the valve caps. Care should be taken, in disconnecting, not to scratch or injure the working surfaces, as these defects will seriously affect the efficiency of the compressor and destroy the leathers. Special care to be taken when replacing rings, both in air pistons and stuffing-boxes, that they are fitted as shown, and that the packing is in good condition and screwed up tight. After replacing the parts, turn the engine by hand to ensure that everything is clear before starting.

Care should be taken that the leathers are the correct size and soaked in oil before being fitted in the high-pressure piston and stuffing-box.

CHAPTER XVIII.

REFRIGERATING MACHINES.

The Dry Air Refrigerating Machine.—This type of refrigerator was one of the first to come into general use, though, at the present time, machines employing chemicals—such as anhydrous ammonia, sulphurous acid, and liquid carbonic acid—are largely used. It is admitted that the coal consumption of the machines using air as the working fluid is greater than that required by the chemical machines; but other considerations must be taken into account when a complete comparison is made. The space taken up is greater, and the weight of machinery, when the brine pipes are included, is also greater, in the case of chemical machines. As regards the cost of upkeep, the necessary chemicals, as well as the coal, must be taken into account. On the other hand, a greater weight of coal must be carried, if an air machine is employed, for the same duty as is performed by a chemical machine under similar circumstances. The air refrigerator has the advantage that no store of chemicals need be carried to make good losses by leakage; also no serious inconvenience can be caused on board by the escape of the working charge. In a warship these latter considerations are of great importance, since this class of vessel may be absent from its depôt for an indefinite period; and, again, the consequences of any damage caused by shot and shell make a vapour such as anhydrous ammonia less suitable.

The principal parts of the dry air machine, and its action, may be described as follows:—Air is drawn into a compression pump, either from the cooling chamber or from the atmosphere; it is compressed to about 50 lbs. per sq. in. (gauge) and delivered to a "cooler." The work necessary for the compression of the air is least if its temperature is kept constant during the operation; consequently, the cylinder of the pump is surrounded by a current of cold water flowing through a jacket. In practice, the temperature of the air is considerably raised during compression, and consequently it is passed through a cooler on its way to the expansion cylinder. The cooler is made of a similar form to that of an ordinary steam condenser, the air passing through, or around, the tubes, the other surface of which is cooled by means of circulating water, supplied by a pump worked from the engine crank-shaft. In consequence of the work done by the air, during its subsequent passage through the expansion cylinder, its temperature is very considerably reduced, according to the nature of the expansion and the point of cut-off adopted. The cold air is finally discharged from the expansion cylinder, through a snow box, to the cooling apparatus or chamber.

It is found that special means must be adopted to get rid of the moisture, carried in suspension by the air drawn into the pump. This moisture would be deposited as ice or snow on the temperature being lowered sufficiently; it is, therefore, important to remove as much as possible before the air is admitted to the expansion cylinder. A certain proportion of the water vapour is condensed in the cooler, from which it is blown out from time to time. In order to further dry the air, an arrangement, known as a "dryer," is fitted between the cooler and expansion cylinder. This apparatus is on the interchanger principle; the cold air discharged from the cooling chamber is caused to flow through pipes in the opposite direction to the current on its way to the expansion cylinder. By this means the initial temperature before expansion is reduced approximately to that of the cold chamber, and—what is of more importance from a practical point of view—most of the remaining moisture is deposited in the "dryer." By this method a very low temperature may be attained. In an alternative arrangement, the air discharged from the cooling chamber, which is comparatively dry, is drawn into the compression pump. In this way a greater weight of air passes through the machine per revolution, and, although the minimum temperature attained is not so low, yet the performance of the refrigerator is theoretically greater than that due to the first plan described above. In spite of the above precautions, ice and snow will be deposited in the exhaust ports of the expansion cylinder and in the snow box, and must be cleared away periodically by the means described later.

It is essential that the cut-off should be early in the expansion cylinder, and the clearance at each end must be as small as possible. To this end the length of the inlet passages is reduced to a minimum; one port in the face is at each end of the cylinder, and a separate Meyer expansion valve works on the back of the slide valve proper. The bearing surfaces of these valves are liable to be pitted, especially on the laps; also, if ice forms on them they may become scored. Any small leak across the slide face tends to the formation of ice, which would raise the valve from its face, slur the sharpness of the cut-off, and seriously impair the action of the machine. For these reasons the various surfaces must be planed up when injured, the ordinary interval being about a twelvemonth. The cylinder face is often made of gun-metal, or phosphor bronze, whilst the valve is of cast iron, so that, if the machine is standing idle for any lengthened period, the valve should be removed from the face to prevent galvanic action. In any case the valve chest cover should be removed for examination of the surfaces at weekly intervals. A special black oil, of low freezing point, is used for the internal lubrication of the cylinders and valves; this oil sometimes forms a hard black deposit adjacent to or on the working surfaces, and it must be removed by chipping. Glycerine is sometimes used for internal lubrication, but if the cold air comes in contact with the cargo the glycerine carried over by it affects the taste of the meat.

In order to improve the sharpness of the cut-off, the inlet and exhaust ports are often made separate, and communicate with a separate slide valve and face. Since most of the ice formed is deposited from the cold exhaust air, it is possible by this means to confine it to the surface of the exhaust valve and passages. The latter valve is then the one requiring most attention, and is liable to be scored on the back surfaces, which are in contact with the bearing strips. A removable cover is generally fitted to the exhaust passage, closing an orifice through which the snow deposit may be removed. It is a very general practice to stop this class of machine after about three hours' work to allow it to warm up and melt the ice off the internal surfaces mentioned. Hot air may be introduced from the compression cylinder, or a steam jet may be arranged to play on the outside of the air passages, when desirable, for the same purpose. The water formed is then discharged through the cylinder drains.

A big leak past the expansion valve may be detected by an expert, when the snow box is opened, by means of the difference in sound between a continuous rush or hiss and the normal regular puffs of the exhaust air; the snow box is opened about once a watch to make this observation.

Types of Machine.—Refrigerators employing dry air as the working fluid are made with the cylinders, either vertically disposed above the crank shaft, or placed horizontally, as may be most convenient with regard to the available space for them. The machine illustrated in section, Fig. 94, and in elevation, Fig. 95, is the pattern made by Messrs. Haslam, and has been fitted in many vessels. The steam engine is compound, with the two cylinders arranged in tandem. Amongst other ships supplied with this pattern are H.M.S. "Powerful," "Terrible,"

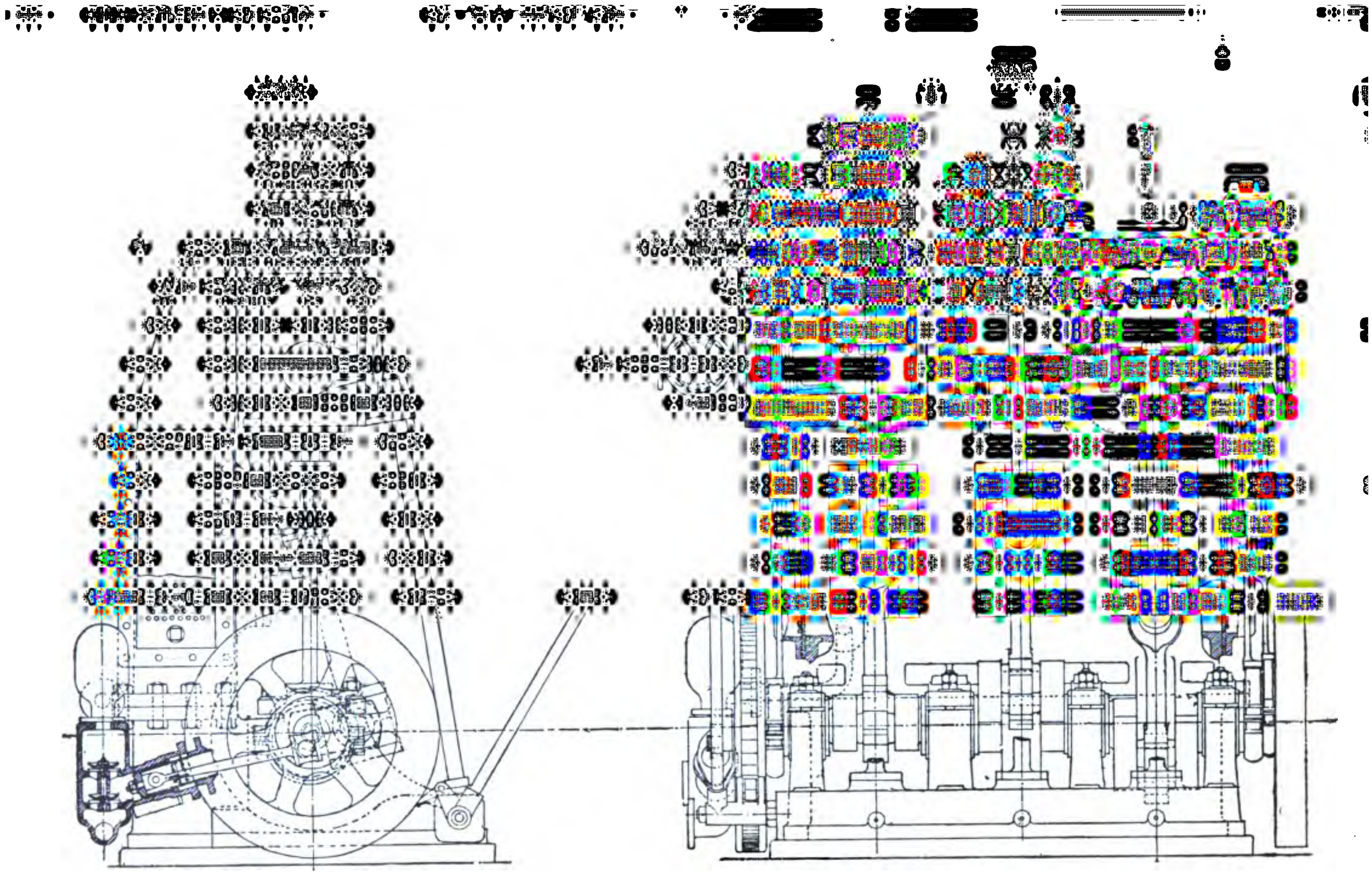
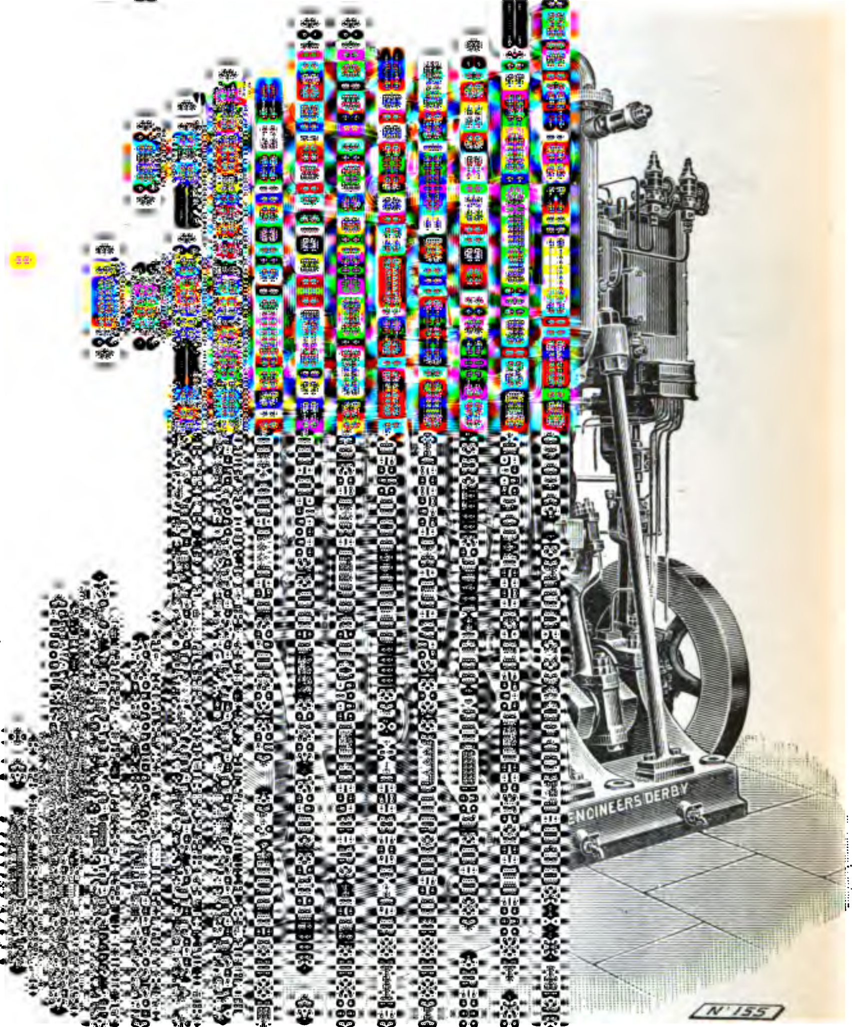


Fig. 94.—Haslam's Dry Air Refrigerator.

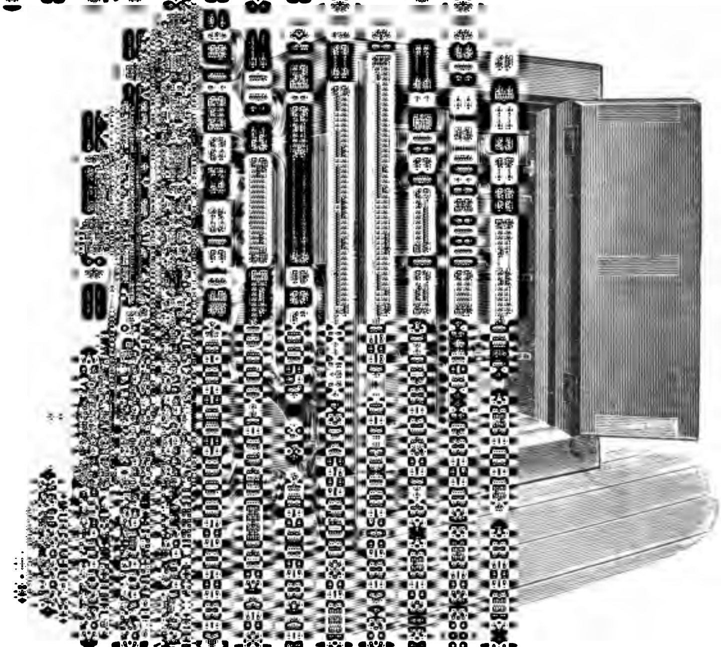
[illegible] the line of stroke is



[illegible] Refrigerator.—Elevation.

[illegible] makers arranged [illegible] an insulated box [illegible] xteen hours.

[illegible] ng a frozen cargo [illegible] nd steam engine, [illegible] y be disconnected



[illegible] or.

[illegible] a simple engine. [illegible] hat as follows :—

[illegible] . 50° Fahr.
[illegible] ump, 350° Fahr.
[illegible] er, 85° Fahr.
[illegible] - 60° Fahr.

[illegible] ently preserved a [illegible] and 200 tons of [illegible] er day, in vessels [illegible]

[illegible] ld Storage."

Notes on Working.—These machines are started from a certain point of the stroke, and must be placed in this position by means of the hand-turning bar. Before starting it is important to ascertain that the jacket of the compression pump is full of water, and the machine must be sent off briskly to ensure a good circulation through this fitting. A large quantity of water is usually deposited by the air in the cooler, dryer, and air expansion cylinder, on starting, and therefore the drains to these parts should be open in readiness. (*N.B.*—The drains on the machine should be left open when it is not working.) These drains are gradually closed as the normal air pressure is attained; subsequently the cooler and dryer are blown out about once an hour. It is important that the water circulation around the compression pump should be good; if this part warms up, the machine should be stopped whilst the circulating pump is overhauled and its gratings are cleared. A cover is generally fitted on the water jacket, through which a piece of hoop iron can be inserted to clear away any barnacles or other obstruction. The inlet and outlet valves of the compression pump are subject to constant vibration which renders them hard and brittle; they should be examined and cleaned about once a week, when they can be changed if their appearance is unsatisfactory. When the machine is at work the best indication of its state of efficiency is the general appearance of the frosted parts, to which the attendant becomes accustomed. The various temperatures are recorded by thermometers, which, however, do not give the temperature of the whole body of air, and, consequently, the attendant relies more on the deposits of ice. The most common defects are broken valves in the compression pump, and a leaky slide valve in the expansion cylinder. The plungers of the expansion and compression pumps are generally packed with Ramsbottom rings and give little trouble; they need not be overhauled much oftener than once a year. The engines are not specially balanced, and a heavy knock may result if the crank brasses are not kept in good order. The air crank brasses need special care since they often tend to warm up; they should be freely lubricated on starting. The clearances, at each end of the stroke, in the compression pump are very small; consequently, whenever the brasses are adjusted, one of the inlet valves at each end of the pump should be removed, and a bent piece of sheet lead should be inserted, to obtain the exact amount of clearance at both ends of the stroke. The nuts securing the covers of the expansion and compression cylinders are often lined with white metal, so that if the clearance is improperly adjusted and the cover is knocked off, the damage may be confined to the white metal thread stripped out of the nut. The glands of the rods of the air cylinders are packed with plaited cotton soaked in glycerine, or in the special lubricating oil; the packing generally lasts some months.

The snow-box must be cleared out about once in a day of eighteen hours, about two to six buckets of snow being removed; the machine need not be stopped for this purpose, since the attendants are not liable to any inconvenience. Persons unaccustomed to the machine may contract severe sore throats if they inhale the cold air. The cold air shutes are cleared whenever they become choked with snow, say once a day. For this purpose the attendants are provided with a special flannel dress and gloves; on arriving in the engine-room, they enter the shutes from the snow-box before they have had time to get in a state of perspiration, the machine having been stopped for some time, say two hours, previously. If the compression pump is drawing from a cargo of fruit, the air is heavily charged with carbonic acid gas; in this case, before the shutes are cleared the machine is caused to draw from the atmosphere for about an hour, in order to clear away the carbonic acid. Any light required should be furnished by a candle, the flame of which will indicate the purity of the air in the chambers. Carbonic acid causes increased pitting of the surfaces of the air cylinders.

The air is distributed throughout the cargo hold by means of adjustable louvres in the shutes; these are opened wider, or closed, according to the local temperatures observed. If a mixed cargo of meat and fruit is carried, the course of the cold air current should be from the meat to the fruit; air which has been in contact with fruit taints the meat.

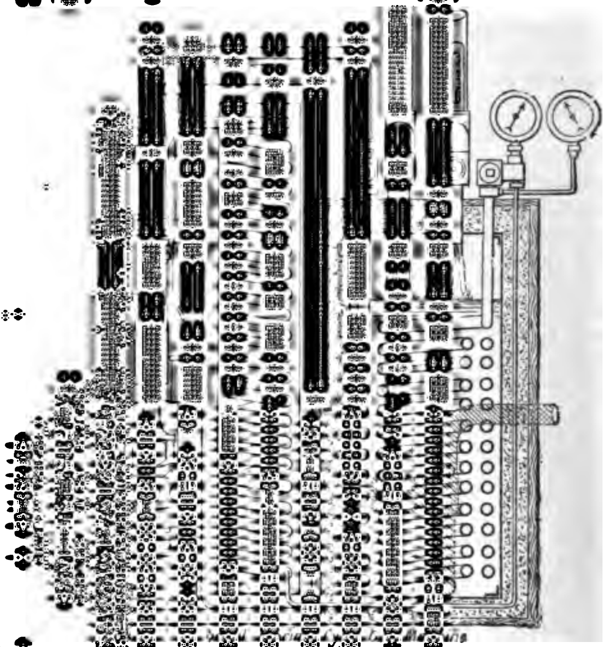
A meat cargo must not be stowed in contact with the refrigerating surfaces; wooden battens are interposed to provide for the circulation of air; any accidental contact results in discoloration and subsequent condemnation of the meat. Any settlement of the cargo indicates too high a temperature in the compartment. The proper temperatures for cold chambers depend on the nature of the stuff to be preserved and are as follows:—

Meat and poultry, 16° F.
Fruits and vegetables, 40° to 50° F.
Fish, after being frozen, 25° F.
Wines, 50° F.

The Carbonic Anhydride Refrigerator.—This apparatus, as made by Messrs. J. & E. Hall, Limited, consists of the following three principal parts:—

(1) The compressor, which in the larger machines is con-

[illegible] sure soundness of [illegible] e smaller machines,

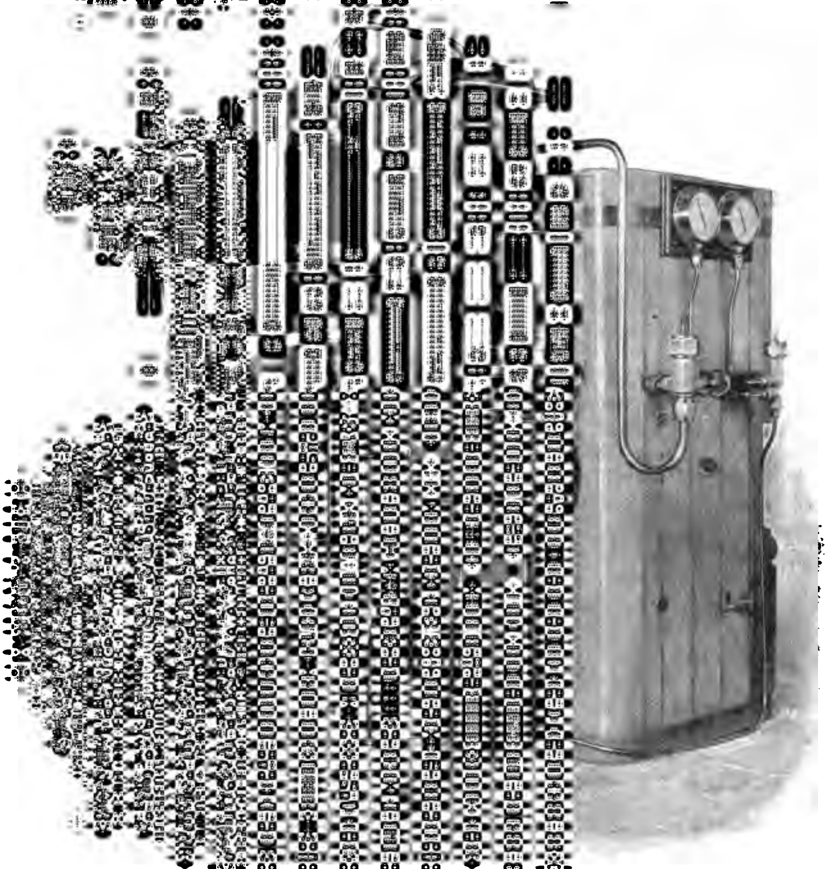


[illegible] frigerator—Section.

[illegible] ought-iron hydraulic [illegible] ating water. Solid- [illegible] circulating water is [illegible]

[illegible] ought-iron hydraulic [illegible] elded by electrical [illegible]

[illegible] through a cycle of [illegible] tively low pressure, [illegible] old brine used for [illegible] high pressure and [illegible] nto the circulating [illegible] lating valve to the [illegible], below that of the [illegible] quid, the remainder [illegible] A small additional [illegible] time, to make good [illegible]



[illegible] gerating Machines.
[illegible] ype.

[illegible] aries from 750 lbs. [illegible] the temperature of [illegible] s subjected to this [illegible] per square inch.

The vertical marine type of machine, illustrated in elevation (Fig. 98) and section (Fig. 97) is that made by Messrs. J. & E. Hall of Dartford. It consists of a single vertical steam cylinder, with the compressor arranged alongside, both secured to a casting containing the condenser coils, which are made of copper. Behind this casting is another, secured to it and containing the evaporator coils surrounded by brine, the casing being efficiently lagged. The evaporator coils are made of wrought iron welded by electrical means into long lengths, so that there are no internal inaccessible joints.

"Machines* of this class driven by a steam engine of about 110 I.H.P. are capable of maintaining a cargo of 1800 tons of meat at a temperature of 10° F., the coal required being about half a ton per day. The cost of the additional CO_2 required during the voyage from Sydney to London was from £11 to £12." These results were obtained in 1896; in 1905 the additional CO_2 required cost only £1. A machine in use on one of the Castle liners in 1905 required 2 bottles, or 80 lbs., of CO_2, 3 gallons of Arctic oil, and ¾ cwt. of calcic chloride for brine, during a period of three and a half months' running.

Notes on Working.—The necessary adjustment of the regulating valve, to secure the desired working conditions, is made by reference to the pressure-temperature gauges, connected to the evaporator and condenser respectively. These gauges each give two readings, the pressure being shown on one circle of figures, and the corresponding temperature on another concentric circle. The evaporator gauge should indicate from 10° to 15° below the temperature of the brine leaving the evaporator; the condenser gauge should indicate about 10° above the temperature of the circulating water entering the condenser. If the machine is overcharged the condenser gauge will give a higher reading and the pointer will oscillate considerably. Under ordinary working conditions the compressor should be cold, or even partly covered with snow, and the delivery pipe from it should be rather warmer than can be comfortably borne by the naked hand. If the delivery pipe is not hot enough the regulating valve should be partially closed; whilst, if the pipe becomes too hot, the valve should be opened.

It is found that the charge of gas needs replenishing, from time to time, on account of the slight leakage which takes place from the joints and glands; also the amount of gas required in the system increases with the temperature of the circulating water. The charge is insufficient when (the valves and leathers of the compressor being in good order) the working conditions, detailed above, cannot be maintained, and the refrigerating

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* *Proc. Inst. C.E.*, vol. cxxix. (1897), "Cold Storage."

[illegible] st, the regulating
[illegible] contains sufficient
[illegible] ot be affected for
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[illegible] n is insufficiently
[illegible] of gas slung near
[illegible] it is then only
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[illegible] above the critical
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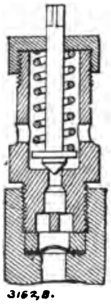

Fig. 99.—Hall's Safety Valve.

the regulating valve should be closed; after a certain number of revolutions, the evaporator gauge will commence to fall, and should then show a fall of pressure of about 1 atmosphere for every 10 revolutions. If the fall of pressure is less than the normal amount, the cause may be found in faulty compressor valves or piston leathers, or may be due to a leak past the regulating valve.

Before removing the compressor piston-rod, the suction and delivery valves on the pump must be closed, and the pressure released by breaking a suitable joint; otherwise the rod, when disconnected, may be driven violently against the end of the cylinder.

The compressor rod should be removed and kept well greased, in a dry place, whenever the machine is not required for some days.

The various joints are made with copper rings, carefully placed between the butting surfaces. About once a week (or oftener with a new machine) these joints, as also the glands and stuffing-boxes, should be coated with a soap lather, when any leaks will be indicated by the bubbles formed. It is important to stop the smallest leak as soon as it is practicable.

The packing rings in the gland of the compressor rod will last for some time, with careful treatment and a smooth rod. A leaky gland is indicated by the loss of the lubricant supplied by the special pump.

The internal parts of the compressor are lubricated with a special oil which has a freezing point not exceeding $-25°$ F. The oil is supplied from a special pressure lubricator, and the valve on the oil pipe should always be wide open. The strainer attached to the pressure lubricator requires to be cleared occasionally. The separator fitted to collect the lubricant oil discharged with the gas from the compressor is best drained by oscillating the handle of the drain cock; if the lubricant is drawn off in a stream, a quantity of gas will probably escape with the oil. The oil collected from the separator should be freed from any water mixed with it, and should then be filtered through four or five thicknesses of fine muslin, when it can be used again. The oil escaping outwardly from the gland of the compressor is caught in a removable receptacle, and can be similarly treated.

The Anhydrous Ammonia Refrigerator.—The action of this class of machine is based on the evaporation of liquid anhydrous ammonia, which abstracts the necessary heat of evaporation from the cold brine used for refrigerating purposes; the gaseous ammonia is subsequently compressed and liquefied in a condenser supplied with circulating water, into which the heat of liquefaction is ejected.

The diagram, Fig. 100, shows the arrangement of the different parts in outline. A steam engine or other motor, not shown in the sketch, is necessary to drive the compressing pump.

The pressure of the vapour of ammonia at 0° Fahr. is about 30 lbs. per square inch absolute, and at 80° Fahr. the pressure is about 150 lbs. per square inch, so that the limits of pressure fixed by the ordinary working temperatures, of the brine and condensation water respectively, are very suitable. On the one hand, the maximum pressure is not excessive, and, on the other hand, the minimum pressure in the evaporator coils is above that of the atmosphere, so that air cannot leak into the apparatus and dilute the working fluid.

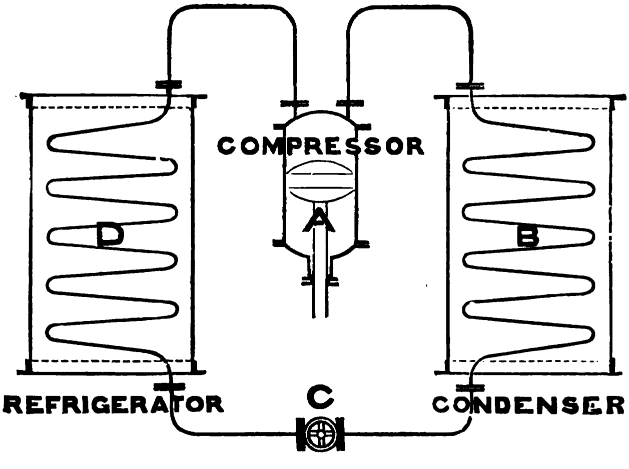

Fig. 100.—Anhydrous Ammonia Refrigerator.

As a general measure of precaution, a water service with fine jets should be fitted to enable the ammonia connections of the machine to be quickly drenched in the event of a sudden leakage of ammonia, the working valve being placed in a readily accessible position.

Water of a temperature not greater than that of the atmosphere should be used for filling the ice moulds. The use of hot water is dangerous.

Hydrogen gas is liable to be generated in the condenser and refrigerator of these installations, and the use of naked lights in the machine-rooms should be prohibited.

[illegible] monia machines is [illegible] t more particular [illegible] upkeep, accounts [illegible] spectively by the [illegible] follow :—

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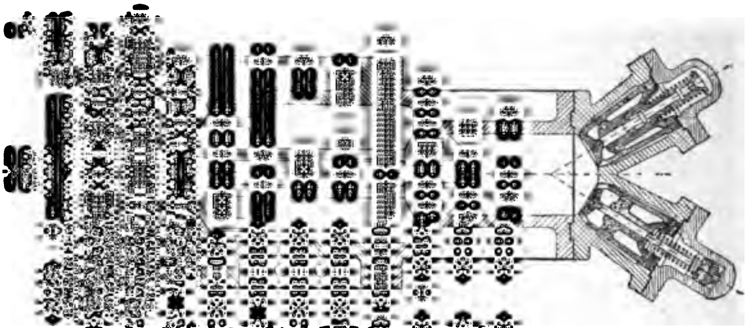

[illegible] pressor.

[illegible] Stuffing-box.

[illegible] ss due to clearance. [illegible] d is forced to the [illegible] ly, the gland is not [illegible] d, and, hence, the [illegible] -acting compressor no gas is drawn into the cylinder until the pressure in the clearance space is less than that in the suction pipes.

The lantern stuffing-box used for the compressor piston-rod is shown in Fig. 102; the recess is kept full of oil. The packing is made of plaited soft cotton, soaked in "Arctic" oil; it will last from four to six months if the surface of the rod is kept in a high state of smoothness. The packing should be cut in lengths which just fit round the rod, with the ends at an angle, as shown in Fig. 103. The greatest care should be exercised to keep the gland, oil, and packing free from grit. The last turn of packing next the gland consists of a "compressor ring" of special make.

The oil used for the internal lubrication of the compressor and gland should have a low freezing point; it must not contain any acid, and must not saponify in contact with ammonia.

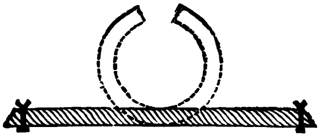

Fig. 103.—Linde's Refrigerator—Packing Strip.

The **condenser** used on board ship consists of coils of wrought-iron tubing enclosed in a cylindrical wrought-iron tank, which is supplied with circulating water around the coils.

The **refrigerator**, or evaporator, consists of a coil of wrought-iron tubing immersed in a tank, through which the cold brine is forced around the coils.

The coils of the refrigerator and condenser should be cleared of any oil or dirt, carried in by the ammonia, by means of a jet of steam blown through each coil, and supplied by a flexible hose. The outside surface of the condenser coils should be cleaned by brushes introduced through the spaces between the coils. The surface of the coils should be covered with a coating of boiled linseed oil to prevent corrosion. Any small area of pitting discovered in the coils should be carefully cleaned, filled with solder, and reinforced by an iron hoop gripping around the weak spot, after which a test pressure of 1500 lbs. per sq. in. should be applied.

The flanges on the ammonia pipes are screwed on. The thread cut on the pipes and in the flanges is tinned, and the latter are screwed on hot. The end of the pipe and the flange are made flush, and are then tinned, and a cup at the back of the flange is filled up with solder. The joints between the flanges are made by means of a special composition ring, but lead wire may be used if the former is not available.

The proper manner of searching for leaky joints is by burning powdered sulphur, spread on a flat stick and passed around the joint. An ammonia leak is indicated by the white clouds of vapour formed. The practice of smelling for a leak is to be avoided, the result of a successful search being more than inconvenient.

Notes on Working.—The machine must be started slowly with the suction and regulating valves shut, but the delivery valve from the compressor to the condenser must be open. When a vacuum has been produced on the suction side of the pump, the inlet valve and then, very gradually, the regulating valve are opened. If the communication between the compressor and the refrigerator is open on starting, the valves of the former are liable to be damaged by excessive pressure. The normal temperature indicated by the gauge connected to the condenser should be about 10° higher than that of the cooling water; that indicated by the gauge on the evaporator should be about 10° to 15° lower than the actual temperature of the circulating brine. The oscillation of the pointers at every stroke should be quite regular. The normal temperatures are produced by adjustment of the regulating valve, which should always be altered very gradually. The compressor delivery pipe should be of the same temperature as the cooling water. If this pipe is too hot the regulating valve should be opened more fully, and *vice versâ*.

If the delivery pipe is too hot and the regulating valve is open beyond the normal amount, the charge of ammonia in the system is insufficient. Additional ammonia is supplied whilst the machine is running by connecting up a reservoir cylinder to the suction side of the pump, or, preferably, to the proper fitting on the rectifier. The reservoir should be slung clear of the machine to guard against any accidental injury to the gauge connections, or other small fittings, the fracture of which might entail the loss of the whole or part of the ammonia in the machine. The greatest care must be exercised for the protection of all small fittings on the machine. The oil carried into the compressor is deposited in an oil collector; in large machines, a rectifier is fitted to effect a more or less continual removal. The rectifier is connected with the suction side of the compressor by a pipe, so as to allow the ammonia dissolved in the oil to be drawn off. The oil discharged from the rectifier should be filtered through wire gauze and muslin, and can then be used again, mixed with an equal part of fresh oil.

During temporary stoppages, the suction valve on the pump and the regulating valve are closed, and should remain closed when the machine is first started, as pointed out earlier. The delivery valve on the pump is best left open during a short interval of rest.

Upkeep.—Should the valves or the pump piston rings leak, the refrigerator pressure will be higher, and the pressure in the condenser will be lower, than under normal conditions; also, if the regulating valve be closed, the refrigerator cannot be entirely evacuated. In such a case, the valves and piston rings should be overhauled; the former are more liable to need repair. The valves are ground in place by means of fine emery powder and sand; they must be renewed from time to time, since the constant vibration to which they are subjected makes them brittle. A broken spring, or valve, can be detected by the difference in the sound it makes when at work. Generally a slight leak of ammonia can be dealt with and the machine approached, if a piece of wet waste or similar material be held over the mouth and nostrils.

Before breaking any joints, to open out any part of the machine, however small, the ammonia must be pumped into another part; or, if this is not possible, it must be discharged below the surface of a quantity of water contained in a suitable vessel. As an instance, to overhaul the compressor valves:—(1) Close the regulating valve, and pump all the ammonia from the evaporator into the condenser; (2) close the suction and delivery valve on the compressor; (3) discharge the residual ammonia from the compressor through an india-rubber hose, suitably attached, and led into a bucket of water; and (4) the valves can now be withdrawn and examined. All the bolts of each joint should be tried, and tightened up from time to time, as found necessary, whilst the machine is at work.

Whenever the machine has been opened out for repair, it must undergo an air compression test up to 150 lbs. per sq. in., before being charged with ammonia. During the air test any leaks are discovered by means of the bubbles blown when the joints and glands are washed with a soap and water solution. The ammonia charge is gradually supplied to the machine after all the air has been pumped out by means of the compressor.

The two principal **systems of preserving cargo** at a low temperature used by the Linde Company are as follows:—

1. The refrigerating coils are immersed in an iron tank containing brine. The cooled brine is pumped through a circuit of 2-in. galvanised iron pipes, laid in the hold and around the cold chamber, and returning to the tanks. These brine pipes become covered with snow, and a process of thawing-off, draining, and drying up is necessary, after a voyage, in order to clean the

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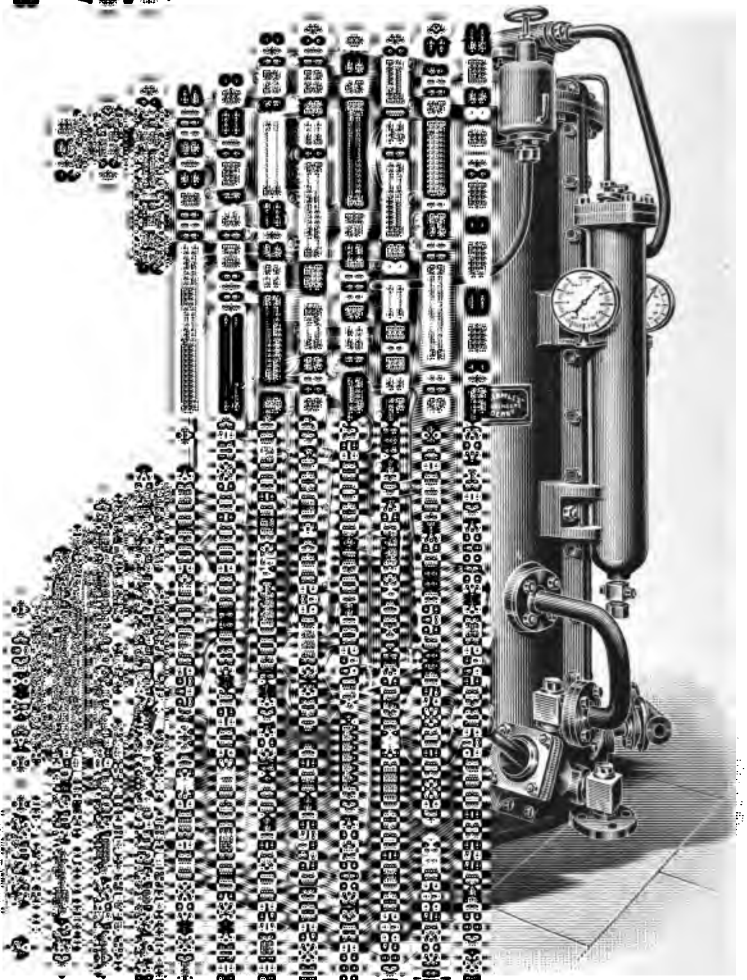


[illegible] igerator,

[illegible] the refrigerating coils [illegible] livered to the cargo holds through well-insulated trunks. The process of "thawing-off" is not necessary, and there are no pipes to be laid in the holds. This system is in use in some of the vessels trading to Australia and New Zealand.

Haslam's Ammonia Refrigerator.—The illustration (Fig. 104) represents a vertical ammonia refrigerating machine designed to form a self-contained apparatus. The back casting is of cast iron, circular in form, and contains the ammonia condensing coils. It is made in two parts, and the back part can be removed to give access to the condensing coils, for cleaning and examination. The front part of the condenser casting is provided with ribs, facings, and brackets to receive the steam cylinder, ammonia compressor, crank-shaft, and other working parts. A pump to provide cooling water is worked from the engine crank-shaft.

The principle of the action of the machine is similar to that of the Linde apparatus; the brine, when cooled, is pumped into a receiver, and allowed to flow over a set of surfaces formed by parallel corrugated plates. Air is circulated over the alternate surfaces of the plates, and cooled to the desired temperature, the moisture carried by it being deposited as snow. The air is then drawn by fans through the cargo holds or freezing chambers, and so passes again to the refrigerating battery of plates. The cold store erected in 1897 at the Victoria Docks, and designed to hold 10,000 tons of meat, is fitted with this system of refrigeration.

CHAPTER XIX.

MACHINERY AND BOILERS OF TORPEDO BOAT DESTROYERS.—WATER-TUBE BOILERS.

Weight of Machinery.—The machinery of these little vessels is very light. Sir John Durston has made a striking comparison between H.M.S. "Warrior" and H.M.S. "Quail" to emphasise the extreme lightness of the latter's machinery. The former vessel was built in 1861, and was of 5400 I.H.P., and the "Quail" is selected as being one of the class of destroyers which steam at a speed of 30 knots when developing about 6000 I.H.P. The "Warrior's" machinery weighed 898 tons—that is, it is more than twice the total weight of the "Quail" complete with stores and crew. The machinery of the latter weighs only 144·3 tons, of which the boilers account for 75·7 tons, including the weight of the water when at working height, which amounts to 11·25 tons.

The boilers fitted in these vessels are of the class of water-tube boilers (called by Sir John Durston the "Express" type), containing tubes of small diameter, and are capable of being used under a greatly accelerated draught without leakage of tubes or other injury.

In connection with these water-tube boilers it has been pointed out that they contain a relatively very small quantity of water. Supposing the engines of the "Quail" to use 20 lbs. of feed-water per H.P. hour, then the weight of water contained, under working conditions, passes through the engines in 12·6 minutes, at full power. It is, therefore, very important to keep the supply of feed-water to the boilers as uniform and regular as practicable. Automatic feed-water regulators have been successfully fitted for this purpose. Various arrangements are described in this book (see Index).

The quantity of feed-water carried in the reserve and feed tanks is very small, from 2 to 3 tons only. It is, therefore, important to prevent waste of water through leaky glands, joints, boiler tubes, or safety valves. The evaporator must be kept in first-rate condition, and must be brought into use early in a long run, so that the amount of water in the reserve tanks may always be ample.

The reserve tank in the later destroyers will hold 4 tons; the additional capacity is intended to provide a reservoir for the water not required in the boilers when running at full power, so that the actual reserve can only be reckoned at 3 tons. There should always be a sufficient reserve of water to fill up the boilers when the engines are eased or stopped.

The supplementary feed-water required is drawn into the condenser from the reserve tank, through a communicating pipe fitted with a small valve. This valve should be adjusted so that the water in the feed tanks never sinks below a fixed point on the gauge glass; if the suctions are well covered there will be a plentiful supply for the feed pumps, and the latter will not draw air from the tanks. The supplementary feed valve must be closed immediately the engines are stopped; otherwise, the condenser will fill up and, on starting, the air pump may suffer.

Difficulty is sometimes experienced with the suction of the feed pumps when the feed-water is of an unduly high temperature, as, for instance, when the engines are standing with steam on them and with the drains open; or, again, if the engines are running and the condenser has an insufficient supply of circulating water. In the former case, the remedy is to use the auxiliary feed pump drawing from the reserve tank until the engines are started; in the latter case, the speed of the circulating pumps may be increased and a diligent search should be made for any open drains. The temperature of the feed-water should not be much lower than 120° F. in order to expel as much air as possible from the water in the feed tanks.

Automatic feed-water regulators require considerable attention to ensure efficiency. Those fitted with a cut-off valve inside the boiler require that the joints of the internal feed pipe should be strong and water-tight. The gland on the spindle fitted for testing the automatic valve by hand should not be packed too tight. The internal steel floats are liable to corrosion, and may become waterlogged or collapsed.

If no automatic feed-water controlling gear is fitted, the chief stokers must be trained to run the feed pumps at a uniform rate. The pumps must not be used spasmodically, since one pump may, in that case, deprive the others of their supply, and, consequently, one boiler will be pumped up quickly whilst the others may be running short.

Filters.—The condensed steam is filtered in passing through diaphragms of Turkey towelling, sponges, or other suitable material, which may be fitted in the feed tanks. These filter cloths are removed at intervals of not more than a month, and clean ones are supplied in their place. It is found that a considerable quantity of oil is separated from the feed-water; most of it obtains access to the cylinder through the low-pressure valve-rod and piston-rod glands, especially at reduced powers.

The density of the water in the boilers must be kept at "nil." If the water in the boiler has 1° or 2° of density, there is a tendency to prime, and it is impossible to work at a rate approaching full power. For this reason the condenser tubes must be maintained absolutely tight; they are generally packed with tape soaked in linseed oil, and the glands must be examined and screwed up frequently.

Priming.—In addition to the water salting up, priming may be caused by greasy or dirty water, which shows no density. The water obtained from the shore is generally unsuitable for small tube boilers, and should not be used unless absolutely necessary; as an instance, the Sheerness water is known to cause priming. For the foregoing reason, and also to exclude air from the boilers, the latter are run up with distilled water, and, whilst working, the make-up feed is always supplied by the distillers. It has been found that the air introduced by the shore water promotes corrosion of the boiler tubes.

Priming may result from the stop valves being opened too wide. If the boiler stop valves are opened to the minimum extent only, priming is less likely to occur; if the speed be increased word can be passed to the stokehold to open out wider. Priming may also result from the set of boilers in one stokehold being forced to supply more than their share of steam. To prevent this irregularity, the same air-pressure must be maintained in the separate stokeholds; air gauges fitted in each stokehold, to show the pressure in the others, would probably be beneficial. It will generally happen that the stop valves on the forward boilers must be opened slightly more than those on the after boilers, since the resistance of the longer line of steam pipe is greater. Whenever the presence of water in the cylinders is indicated by the sudden thumping set up, the engine drains should be immediately opened, and the separator should be blown through. If the cylinders are not immediately cleared, the engines must be eased, otherwise incipient fractures may be caused, which will develop later into serious defects.

Stoking.—The coal must be supplied to the fires in small lumps, according to a regular system, and must be uniformly spread over the fires when thrown from the shovel. The fires must be kept very bright; until this art is acquired by the stokers, flaming at the funnels will be liable to occur. The coal must be supplied quickly, in small quantities, at short intervals.

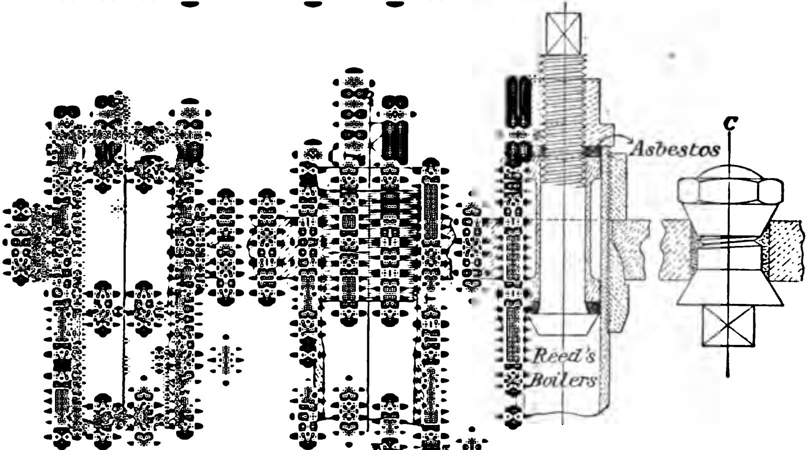
If the engines be stopped suddenly and remain motionless for some time, the steam pressure may be controlled by raking a hole in the middle of each fire-grate, this device being employed only when the more legitimate checks have been applied.

Flaming may be due either to irregular heavy firing or to bad coal. Air leaks at the junction of the funnel and uptake are also a contributing cause.

The proper thickness of fire for full speed varies with the different types of boilers. Approximately in a Normand boiler the fires should be about 18 inches thick; in a Thornycroft boiler about 12 inches is the proper thickness; and in a Reed boiler about 8 to 12 inches is sufficient. Each fire should be distinctly thicker at the back than at the front of the grate, and the fire should always be kept well clear of the dead plate to prevent burning, both of this fitting and of the flame ring around the opening for the furnace door. This necessity cannot be too frequently pointed out to stokers under training. The fires of all boilers in the same stokehold should be of the same thickness, otherwise the air pressure will not be suitable to each and the distribution of draught will be unequal.

A spare stock of fire-bars, bearer-bars, baffles for furnace doors, and flame rings should be maintained, as the wear and tear of these articles is rapid and steady.

If a tube should burst, the water in the boiler will be immediately discharged into the furnace and will pass out of the funnel as steam. This accident may occur without attracting the notice of the men in the stokehold, but the unusual spectacle should attract attention on deck; consequently, a communication with the deck should be arranged, so that the fires can be immediately drenched and drawn before the tubes are destroyed. After such an accident the tubes will generally be found bent in every direction, but they should by no means be condemned without further trial. A case in point has occurred; after the faulty tubes had been removed and the holes plugged, the remainder were carefully straightened in place by wooden mallets, and the boiler stood the test pressure under water without further work of any sort. Sound tubes were then fitted, in place of those cut out, and the boiler was used and proved quite water-tight. In case such an accident happens to one of a set of boilers, it is of importance to shut off the feed supply to the damaged boiler and to attend carefully to the water level in the rest; otherwise, a similar mishap is likely to occur to others of the set. On subsequently testing a damaged boiler, the burst tubes may be found by opening out the steam dome and lighting a small smoky fire of straw in the furnace. The smoke will [illegible] the burst tubes, which [illegible] 105 are supplied to [illegible] ores for the purpose [illegible] Pattern C is used [illegible] ible and the defective [illegible] are of more general [illegible] into the end of the [illegible] tern B requires the [illegible] be end in place; the [illegible] end. In some cases [illegible] they are flush with



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[illegible] 1901, directs that— [illegible] ends are to project [illegible] f an inch, and before [illegible] ned with a solid drift [illegible] progress and on the completion of the tubing an inspection is to be made to see that each tube end has been well rolled on the inside of the chamber, and that it is expanded close to the edges of the hole on the outside." The average life of a set of boiler tubes may be estimated at about six years with proper care and attention, though cases of more rapid wear have occurred. It frequently happens that from two to four rows nearest the fire require renewal at an intermediate period. The parts of the boilers which deteriorate most rapidly are as follows :—

The furnace fittings in all types alike.

Normand Boiler.—(*a*) The ends of the tubes in the lower drums near the point of entry of the auxiliary feed-water supply, and the interior surfaces of these tubes at their lower ends; (*b*) the upper ends of the tubes in the steam drum near the automatic feed apparatus.

Thornycroft Boiler.—(*a*) The upper interior surfaces of the tubes at the top bend above the water level; (*b*) the tube ends in the steam drum near the water line and around the automatic feed apparatus; (*c*) the top interior surface of the bottom drum between the outlets of the downcomer tubes and the ends of these tubes.

Reed Boiler.—(*a*) The interior surfaces of the lower ends of the tubes just above the constricted portion; (*b*) the thread on the tube ends, both top and bottom. The fire rows, in this type, are more liable to deterioration.

Abnormal corrosion in small tube boilers can be arrested by the proper fitting and distribution of zinc slabs. The addition of lime to the feed-water in the feed tank has been found beneficial, as in the case of Belleville boilers; the quantity of lime introduced must be carefully regulated to guard against any risk of choking the tubes with sediment, about 1 lb. per diem for each 500 H.P. developed is sufficient (*S.M.*, Art. 224*a*).

The preservation of the boilers when not in use is of the utmost importance; the method adopted is described on p. 167.

Engines.—Since the number of revolutions per minute at full power is as high as from 350 to 400, it is difficult to ascertain the state of the bearings by touch. All oil-ways must be carefully placed and must be of sufficient width, depth, and extent; the supply holes should be enlarged towards the working surface of the bearing, the channels should be cut fairly deep near the supply hole, and should extend to within a distance of about half an inch of the edge of the white metal. The illustrations (Fig. 106) show arrangements which have worked well in practice. Channels should be cut in the slipper face, as well as in the fixed guide of the crosshead bearing. Berlin the oil cups with

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Excessive vibration of the after part of the vessel may be due to the foregoing defect, or, sometimes, to the shaft running out of truth. A probable cause of the latter defect is faulty faces on the couplings, which may need refacing in the lathe. The shaft should be revolved in place, and the fault localised by scribers rigged up, inboard and in the dry dock, to touch the shaft at various points of its length.

Excessive vibration is sometimes due to bent or broken blades of the propeller, a loose propeller, or to looseness of fit of the steel bush in either the A frame or stern tube.

Cleaning Boilers.—The boilers are emptied and opened out at intervals of from three to four weeks. The interior of the steam space is thoroughly cleaned by narrow scrapers, the tubes are swept with brushes, or scraped by bent wires, passed through them from both ends. If the tubes are so much bent as to prevent the passage of a brush they may be cleaned by means of a powerful jet of water directed into each in turn. The dirt is washed out through the small doors on the water pockets, by means of a similar jet of water. The zincs are treated as already described in the case of tank boilers, and the interior of the steam dome is examined in a similar manner. In addition, for a thorough examination, the black scale formed on the outside of the tubes is removed. Flat brushes with wire bristles are used between the rows for this purpose; if they prove too pliant, flat strips of mild steel, about $\frac{1}{16}$ inch thick and an inch wide, can be made into rasps by the use of a centre punch, until the surface is like that of a nutmeg grater. These rasps will readily remove the black scale. When the outsides of the tubes are clean, they are carefully callipered to detect any diminution of diameter caused by oxidation, such as occurs when steam is passed over red-hot iron in the manufacture of hydrogen gas.

A good deal of soot lodges between the rows of tubes and must be removed by suitable hooks, when the grates are cleared out.

Some of the tubes should be removed from time to time, and cut lengthwise and crosswise to ascertain the thickness of the metal and state of the surfaces.

The feed tanks and reserve tanks should be emptied and thoroughly cleaned out once a month.

The brickwork in the furnaces of a water-tube boiler requires more attention than that of the tank boilers; relatively there is more brickwork in the former. Ordinary firebricks of various thicknesses are now used. Both the front and back walls of the combustion chamber are formed of bricks, and there is a row all round the fire-grate, to protect the joint of the bottom tube plate with the water pocket.

The bricks are set in a mixture of two parts of Stourbridge fireclay to one part of cement (ordinary fireclay is useless); they are rabbetted together by iron strips let into the adjacent ends, and, at regular intervals, are secured in position by bolts sunk in the bricks, protected by fireclay, and passing through the boiler casing. The bricks on the vertical front and back of the combustion chamber require support, to prevent the surfaces buckling. For this purpose angle-iron shelves, or partitions, bolted to the casings may be fitted; the width should be 1 inch less than the thickness of the brick, so that the iron can be covered by fireclay. An angle-iron arch is placed above the furnace door so that the bricks are supported from the grate level and are not shaken down when the door is banged.

The surfaces of the uptake casings become very hot; if the paint peels off it must be renewed to prevent the plates rusting.

Safety Valves.—It sometimes happens that these fittings leak under steam when set to the adjustment found necessary on testing them in the shop. The effect of the higher temperature, to which the springs are exposed when in place and under steam, frequently necessitates a further compression of about $\frac{1}{8}$ of an inch, and the final adjustment should, therefore, be made under working conditions.

The ejectors fitted to pump out the compartments of the vessel should be tried whenever the feed-water wasted by them can be spared; they act very well, even those in the stokehold, where the suctions are often covered with coal dust. A screw-down non-return valve is fitted in the ejector discharge pipe, by the use of which steam can be blown through the suction pipe to clear the strainer. The ejector, used as a pump, has a very low thermo-dynamical efficiency, because the heat, given to the water by the condensation of the steam used, is thrown away and may even be prejudicial; the consumption of steam may be from 1200 to 1500 lbs. per H.P. hour.*

The author's experience is that the steam valve should be opened out smartly to obtain an immediate flow of water.

The cement in the bilges should be frequently removed to enable an examination of the plating to be made, and great care must be taken to keep the framing properly protected with a good coat of paint.

The drill test of the boilers is carried out in accordance with Art. 966 of the "King's Regulations."† A report must be made on form S. 356A, B, and C when the test is due, and the date of the last drill test quoted. The following directions are carried out:—It is to be distinctly stated whether there are any symptoms of internal or external corrosion going on, the condition of the boiler with regard to deposit, the condition of the zinc slabs, and the number which require to be renewed are to be reported.

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* See Peabody's *Thermodynamics of the Steam Engine*, p. 164.

† See also Art. 301, *S.M.*

The parts drilled are:—Steam reservoirs, water reservoirs, permanent tube connections between reservoirs; the existing and former thicknesses being reported in each case. The thicknesses of the tubes in each row are also reported with the existing and former weight per foot of length; for this purpose a transverse row is removed and the tubes are cut up by a band saw, both lengthwise and across, as required for examination and weighing.

A general description of the following parts is given:—Boiler casings, furnace fittings (including brickwork), funnel and uptake, zinc slabs; and an estimate of their probable durability is made.

Sketches are to accompany the report, showing the location of the holes drilled at each test and the position of any plugged tubes.

NOTES ON THE CARE AND MANAGEMENT OF BELLEVILLE BOILERS.*

Preparing for Steaming—Filling Boilers.—*Boilers that are not fitted with economisers* are filled in the first instance, when no steam is available, from the reserve feed tanks by means of a hand pump delivering through a hose, or by means of a hose leading from the fresh-water main on the dock side, the hose being attached to the boiler drain valve on the sediment box, which has a connection for this purpose. When a boiler is being filled, the air cock on the top of the steam collector should be opened to allow the air in the boiler to escape, and the steam stop valves and blow-off cocks should be closed.

Boilers fitted with economisers, and with no steam available, can be filled in the first instance by attaching the fresh-water hose led either from a hand pump or from the dock side to a connection which is fitted on the drain pipe leading from the cold-water collector at the bottom of the economiser, the drain valve being kept open during the process of filling and also the air cocks on the tops of the hot-water collectors of the economisers and the steam collectors of the generators.

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* These notes are contributed by Engineer-Captain Edwards, R.N., of H.M.S. "Bulwark," Engineer-Captain Afloat, Mediterranean Fleet.

As soon as the economisers become full, the water will overflow from the hot-water collectors, through the feed check valve on the steam collectors into the steam collectors, and thence through the downcomer tubes into the feed collectors and upwards into the generator tubes, where its height will be indicated on the water gauge glasses. As soon as sufficient water is admitted, the drain valves on the economisers should be closed and the process of filling discontinued. If the boilers have been standing for any time with water showing in the gauge glasses, it should be always ascertained by opening the drain valves of the economisers whether they also are full of water, and if there is any doubt about this the filling hose should be applied. Cases have occurred when the economisers have been partly or wholly emptied through leaky doors, or through the drains, while standing with water in them, and the effect of lighting up a boiler with its economiser partly or wholly empty (although water at the time might be showing in the gauge glasses of the generator tubes) would be to burn, distort, or destroy the economiser tubes.

If steam is available in any boiler, the other boilers can be filled by means of the feed pumps, the water for this purpose being taken either from the main feed tanks or from the feed reserve tanks, and being pumped into the boilers through the ordinary feed arrangements. This method applies to all boilers whether fitted with economisers or not.

Running down Boilers, which are full up, to Working Level for Steaming.—*In boilers not fitted with economisers* it will be necessary, if they are quite full of water, first of all to open the air cocks on the tops of the steam collectors. A hose should then be connected to the boiler drain valve on the sediment-box and led thence to another drain connection leading to the feed reserve tanks, through which the water can be emptied into these tanks. If it is not desired to save the water, it can be discharged through the boiler drain valve direct into the bilges.

If the boilers are fitted with economisers, the water can be lowered to the desired level in the generator tubes by the same methods, observing that it is necessary to see that the drain valves on the cold-water collectors of the economisers are closed, and also that the graduated feed cocks or valves on the feed pipe leading to the boilers are likewise closed, so that there may be no danger of running water out of the economisers.

It will be sufficient for lighting fires if from 1½ to 2 inches of water show in the gauge glasses.

Laying Fires.—The coal to be used for this purpose should be broken into lumps about the size of a man's fist, and should be spread evenly over the grate to a uniform thickness of about 4 inches. The portion of the grate near the furnace-mouth should be "wooded and topped," as is done in the grates of cylindrical boilers, but care should be taken to keep the fuel clear of the dead plates, in order to prevent the furnace doors being burnt.

As soon as fires are lighted, the smoke-box doors and ashpit doors should be shut, the furnace doors being kept open. When the fires are sufficiently alight and partly burnt through, they should be spread, by means of a rake, evenly over the grate surface so as to cause ignition through the whole of the coal on the grate. The furnace doors must then be closed and the ashpit doors opened, the amount of opening ultimately depending upon the rate of combustion required, but they should be only slightly opened to begin with. If it be necessary to raise steam as quickly as possible, firewood may be placed over the grates as well as on the fronts of the furnaces for "topping up," but, as steam can be raised in a Belleville boiler in about thirty minutes, there is no necessity except for urgent reasons to force the generation of steam, as such a procedure frequently causes "hammering," and possible damage by shock inside the tube elements.

Should extreme haste be necessary, and steam be already available in some other of the boilers, the fans can be started to increase the draught, after fires are spread, but such a proceeding must be undertaken with caution, and only when absolutely necessary.

Necessity for Warming up Engines.—Before lighting up a group of boilers, it is advisable to slightly open out the steam stop valves and connect up the systems of steam pipes in order to warm them gradually as steam is formed, and the air cocks on the steam collectors should also be kept open until steam commences to blow from them, when they should be closed. The boiler stop valves should also be worked to ascertain that they are not stuck on their seatings; at the same time, if no boilers were previously in use for auxiliary purposes, it is advisable to keep the stop valves on one group of boilers closed until sufficient pressure is obtained in this group to work the feed pumps and keep up the water supply required by the whole of the boilers in use. The amount of water contained in each Belleville boiler is so small that, unless this precaution be taken, a risk is incurred of emptying boilers whilst warming up a large system of steam pipes and main engines.

Starting Feed Pumps.—As soon as the steam pressure reaches 50 lbs. per square inch, the feed pumps should be started, and when this has been done, and it has been ascertained that the boilers are being fed with water, the steam stop valves of this group can be gradually eased off their seats and opened as the steam pressure in the other groups becomes equal, the generation of steam pressure in the various boilers being regulated by the draught plates on the ashpits, or by the opening or closing of the furnace or smoke-box doors if necessary.

Starting Main Engines.—After the main engines have been warmed through in readiness to start, it will be necessary to try the air-blowing engines, or, as they are sometimes called, the "gas mixers." As soon as the main engines are under way it will be noticed that the water in the gauge glasses of the boilers will rise. It is advantageous to keep the water level in the boilers fairly low, say 1½ to 2 inches in the gauge glass, as there is less tendency for the boilers to prime, and the steam generated is dryer. As soon, therefore, as the water rises in the gauge glasses after starting engines, the feed valve of the automatic regulator should be partly closed for a time, until the water has descended well into the gauge glass; it should then be opened, and the desired water level should be obtained by arranging the lead weights of the feed regulator; the more weights that are placed on, the lower will be the water level, and *vice versâ.*

Uniformity of Water Level.—It should be attempted in all cases to work with a uniform level of water in the gauge glasses, and to arrange the lead weights so that the feed regulator will preserve the desired water level automatically. The number of weights on the regulator will vary with the rate of evaporation of the water in the boilers, and a convenient expression whereby to remember how to arrange this is—"*higher rates, less weights; lower rates, more weights.*" As soon as the engines have reached the speed at which they are required to be run, the air blowers for the generator tube nests should be set to their proper rate of working; this rate is shown in a subsequent table, and depends upon the amount of coal which is being burnt per square foot of grate per hour.

Stoking.—As in laying fires, the coal should always be kept clear of the dead plates and as level as possible all over the grates, and the fires should not be too thick, especially at the fronts of the furnaces, where it would cause damage to the inner portions of the furnace doors, and also to the nickel joints and sleeve joints of the elements. In firing up, care should be taken to cover up all the air holes and bare spaces that may exist on the grates, and at least once an hour, or more often if necessary, the fires should be levelled by means of the light two-pronged rake or "devil," which is supplied for the purpose.

It will probably be found that a more even distribution of coal is obtained, when "firing up," by throwing the coal well back on the grates. This ensures that the backs are covered, and a certain quantity of coal also drops on the middle and front parts of the grates.

Systematic Firing.—The best results as regards steam generation and economy of fuel are obtained by adopting a regular system of "firing" at equal and frequent intervals of time, the length of the interval and the amount of coal placed in each separate "firing" depending upon the amount of grate surface in use, and the activity of combustion desired.

Each furnace should therefore be "fired" at regular intervals through each of its doors in succession, with equal weights of coal, usually not less than three or more than five shovelsful of 10 lbs. each at a time. As an example, we may take a stokehold having four boilers in it, and each boiler having four furnace doors numbered as in the following plan:—

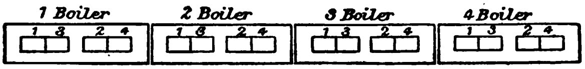

Fig. 107.

The furnace doors should be numbered as shown above, figures in brass being either fixed upon the furnace doors or upon the smoke-box doors immediately above them.

It may be assumed that the time interval has been fixed at (*a*) minutes, and that (*b*) shovelsful of coal are necessary for each firing through each separate door.

The "firing" signals can be given by ringing the stokehold telegraph—a man being stationed for this purpose at the telegraph in the engine-room and having a clock near him with the perimeter of its dial divided off with intervals of (*a*) minutes each.

At the first ring all furnace doors numbered 1 are fired through in succession with (*b*) shovelsful of coal each, commencing with No. 1 door at the left-hand side of the stokehold and going to each No. 1 door from left to right, across or along the stokehold until all No. 1 furnace doors have been fired through, care being taken that there should never be more than one furnace door open at a time. At the next ring all No. 2 doors are fired through, and at the succeeding ring the doors marked No. 3 are fired; and, again, with the fourth ring, all doors marked 4 are fired one after the other. This completes one firing of all furnaces of all boilers; and, at the next ring, the cycle commences again, the interval between successive rings depending on the rate of combustion required.

The officer in charge of the stokehold is responsible that the proper order of firing is kept.

An automatic stoking indicator and regulator is now being introduced, which will probably supersede the improvised method, just described. The "controller" or transmitter of this apparatus is electrically attached to a clock in the engine-room and the receiver consists of a gong and indicator in the stokeholds, which latter shows the furnace to be fired at regular intervals and in definite rotation. The intervals of time are arranged and controlled by the engineer-officer on watch in the engine-rooms, and the rotation of firing is effected by the system of numbering the furnaces.

It has been found in practice that the range of the instrument should provide for a complete round of firing in an interval varying from three to twelve minutes.

This regular and systematic method of firing is especially necessary with a type of boiler which has only a small amount of space above the grate for the combustion of the fuel gases.

A Belleville installation of boilers requires careful firing, because the power is spread out amongst a large number of boilers contained in many different stokeholds, constant supervision by engineer-officers being therefore impracticable, the men should be trained to work on a system which by practice will render the stoking as automatic as possible. It will probably conduce to economy of fuel and more careful and better stoking if not more than one skid of coal per boiler be allowed on the stokehold plates at a time. The fire-irons, with the exception of the pricker and slice, should be as light as possible, a light two-pronged rake, called a "devil," should be supplied for the purpose of raking over the fires and keeping them level and at a uniform thickness, for ordinary purposes, of about 6 inches.

Air-blowing Engines or "Gas Mixers."—Air for combustion is supplied from below the grate, either by natural means or by an assisted draught produced by fans. The air above the grates is supplied by the blowing engines or gas mixers for the purpose of mixing up the furnace gases and rendering their combustion more complete. It is delivered by the blowing engines into pipes and discharged through nozzles projecting into the furnaces immediately over the furnace doors, and it is also supplied to the economisers below their tubes. The pressure at which the air is pumped into the furnaces should be varied in accordance with the rate of combustion of the coal.

Air-blowing engines should always be kept at work for the furnaces whether the rate of combustion be low or high, as by their use economy of fuel is obtained; there is also less tendency to make smoke and the heating surfaces of the tubes are kept cleaner. The following table shows the pressure of air which should be supplied to the furnaces according to the amount of coal burnt per square foot of grate surface:—

Coal Burnt per Square Foot of Grate per Hour, in Lbs.	Air Pressure in Lbs. per Square Inch.
10 lbs. and under, .	5
Over 10 ,, ,, 15 .	6 to 10
,, 15 ,, ,, 20 .	10 ,, 13
,, 20 ,, ,, 25 .	13 ,, 15
Above 25 ,, ...	15 ,, 17

Heavy firing not only wastes fuel and makes smoke, but tends to cause flaming and overheating of the funnels and burning of the boiler and uptake casings, and it likewise renders the task of keeping steam more difficult.

Sight holes are provided in the smoke-box doors, from which the condition of the fires can be observed. The air supply to the furnaces, both from below and above the grates, should be so regulated that the appearance of the furnace is similar to the white heat of the incandescent carbon in an electric lamp, the glowing fuel should be without smoke or dull red coloured flame; either of these appearances indicates that too much coal is being used, or too little air is being supplied for its combustion.

Drawing Ashes.—Ashes should be drawn at least once an hour. It is important to keep the ashpans clear of ashes, and also to use water in them.

Water in the ashpans not only tends to preserve the furnace bars from overheating, but it provides a plane surface for the draught through the ashpit doors to strike upon, and thereby effects a better distribution of the draught of air underneath the grates than would happen if it were to impinge upon a hot and irregular surface of glowing ashes in the ashpans.

Draught Plates.—It is a matter of common experience with Belleville boilers that better results are obtained, as regards the ashpit draught, if the draught plates are sloped at an angle instead of being kept wide open, and it is more advantageous to increase the draught by working the fans faster than to open the draught plates wide. It will generally be possible to work each group of boilers so that their ashpit doors are open at the same angle, but should it be found that uniformity cannot be obtained, the doors nearest the feed float-boxes should be kept open a little wider than those more remote.

Cleaning Fires.—It will probably be found necessary to start cleaning fires when the ship has been under way about eight to sixteen hours, but this must be judged by the appearance of the grates and whether clinker is being rapidly formed in them. It is always better, especially at the beginning of a long run, to commence cleaning fires too soon than too late.

A good general rule is to clean fires after 140 lbs. of coal per square foot of grate have been burnt.

The slice should be used as soon as clinker commences to form in the fires, and the loosened clinker should be withdrawn by the "devil." If the operation of "slicing" be begun at a sufficiently early period, it will not generally be necessary to completely gut the furnaces by pulling all the burning fuel out upon the stokehold plates when cleaning fires.

It will be advisable to arrange that not more than one of the furnaces leading to each funnel is cleaned at a time, and the whole of a furnace should be cleaned in two successive watches of four hours each—*i.e.*, one-half of the furnace in each watch. On starting to clean a fire, the feed check valve on the boiler which is being cleaned should be closed slightly, and the ashpit door under the furnace should be closed. The coal above the clinker on the grate should be pushed by means of a rake above the opposite portion of the fire, the clinker should then be loosened by means of a slice, and should be raked out on to the stokehold plates and damped down by the ash-cooling hose; the good burning coal is then pulled back from the opposite side of the fire to cover the portion of the furnace which has been cleaned; the whole grate should then be levelled up with the "devil" and fired up lightly with coal at short intervals until the fire has regained its normal thickness; the ashpit doors should then be opened to the proper angle and the feed check valve also restored to its normal opening. The operation of cleaning fires must be performed as quickly as possible, and the first part of the fire to be cleaned should be that nearest the feed float-box. The second half of the fire is naturally cleaned in a similar manner to the first half. If the boiler has three furnace doors, clean the middle part first, then the part nearest the float-box, and lastly the remainder.

If the run of the ship is to be of short duration, it may only be necessary to clinker the fires, in which case the coal in the fires should be pushed to the back of the grate, and the clinker loosened and withdrawn, then draw the fire to the front of the grate, loosen the clinker at the back and withdraw it over the fire; subsequently level the fire with the "devil," and fire on lightly at intervals until the fire has attained its normal thickness.*

Before starting to clean fires it is most necessary to shovel the coal away from the stokehold plates immediately in front of the furnaces to be cleaned, as otherwise good coal will become mixed up with burning clinker and be lost. The petty officers and stokers should be trained always to keep the stokeholds swept up and the coal for the boilers lying along the plates in an orderly line in front of the furnaces. As previously recommended, not more than one skid of coal should be kept in front of each boiler, so ensuring, in addition to a neat and orderly stokehold, that the coal will be used more economically; moreover, a clean platform for the men to work on will be provided, and the fatigue of stokehold watchkeeping will thereby be decreased.

Scraping Bottoms of Tubes.—It will be found, especially after the ship has been under way for some time, that a considerable amount of scoriæ will attach itself to the lower portions of the generator tubes, especially those which are nearest the fires. This can either be removed by small scrapers specially made for the purpose, or by using old steel wire-ribbon brushes which have become too much worn for cleaning the interior portions of the boiler tubes.

It is desirable to open only one smoke-box door in one boiler at a time, for the purpose of using either the scrapers or the tube brushes. These instruments are inserted in the triangular spaces between the lower junction boxes, and are then worked backwards and forwards against the dirty lower parts of the tubes. This operation must be quickly performed, because the steam pressure in the boilers will drop if the smoke-box doors are kept open too long.

Sudden Stoppage of the Engines.—Whenever it is necessary to ease or stop the generation of steam in the boilers, owing to sudden stoppage of the engines or other causes, this can be most effectually done by opening the smoke-box doors and closing up the doors of the ashpits.

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* It should be noted that some engineers prefer, when steaming easily, to clean fires in a different manner, as follows:—

The fire being burnt low, the grate is completely cleared by means of the "devil" and rakes, the furnace is then laid and primed with fresh coal, and the fires are lit up with glowing fuel taken from an adjoining furnace. The operation is carried out with great smartness, and the steam stop valve on the boiler is not shut off.—Author.

Banking Fires.—It is not advocated that the practice of banking fires should be frequently indulged in, but, whenever it may be necessary to do so, the fires should be banked well at the back of the grate.

Brickwork.—The brickwork of the furnaces of boilers should be periodically examined by the petty officers on watch in the boiler-rooms, in order that no damage may occur to the boiler casings in the event of the brickwork being defective. In such cases the boiler should be put out of use and repaired.

Sweeping Tubes.—At sea, when under steam, the tubes of both generators and economisers are swept by means of an air jet, supplied through a nozzle and flexible hose attached for this purpose to the delivery pipes of the air-blowing engines or gas mixers. The nozzle is inserted between each row of tubes in succession, and the soot is blown up the funnels. The air hose for this purpose should be at least 2 inches in diameter.

In harbour, when the boiler fires are extinguished, all deposits of soot should be cleaned out of the uptakes, and the exteriors of the tubes of the economisers and generators should be swept by brushes and thoroughly cleaned.

Smoke Baffles.—After the operation of sweeping by brushes is completed, it should be the practice to inspect the perforated smoke baffles which are fitted in certain positions in the tube nests of the generators, in order to see that they are in good condition and in their proper places. Each generator tube lying in the horizontal row upon which the smoke baffles are placed is fitted with a ring or collar, shrunk on to it, and each baffle is fitted with a lug at one end, the lug on the plate resting upon the ring on the generator tube when the baffle is in its proper position; gauges may also be made for measuring the distances of the baffles from the respective fronts of the boilers as a readier means of determining whether the baffles have been shifted from their right places. The correct position of the baffles should be indicated in the drawings of the boilers supplied to or made by the ship's staff.

These perforated smoke baffles are fitted for the purpose of intercepting the furnace gases and causing them to take a more sinuous path in their passage from the grate, through the nests of tubes, to the funnels; they also assist to mix the furnace gases. It will thus be seen that a proper disposition of the smoke baffles adds considerably to the efficiency of the boilers and reduces the coal consumption.

Harbour Baffles.—When the boilers are in use for auxiliary purposes in harbour, the rate of combustion is generally low, and it has been found economical of fuel and beneficial as regards the production of smoke to fit additional portable baffles on the tops of the generator tubes, leaving only a space about 1 foot wide at the front end of the boiler for the passage of the furnace gases. A saving of 15 to 20 per cent. of fuel has resulted in some cases.

Sediment-boxes.—When steaming, especially if the boilers are new, it will be found necessary to frequently blow through the feed float-boxes and the sediment-boxes, as a large amount of muddy deposit from tube joints and from lime used in the boiler water usually accumulates in these boxes. If this deposit is not blown out, it might either collect under the feed float and interfere with the proper feed supply to the boiler, or it might reduce the circulation of water, or form a deposit in the interiors of the generator tubes.

Under normal conditions it will be sufficient to open and shut the blow-off cocks not more often than once a watch, and they should be shut immediately after they are opened, in order to save water.

Corrosion.—This is generally due to the accidental introduction of sea-water into the boilers, or to the presence of air in the feed-water, or to impurities in the feed-water such as the oil from the engines which may escape the feed filters; and, again, to faulty treatment when the boilers are out of use. These causes should, therefore, be eliminated as far as is possible.

Lime.—It is the practice to use a certain amount of slaked lime in solution with the feed-water in order to check corrosion in the boilers. The amount of lime used depends upon the state of the feed-water. It is necessary that the lime should be of good quality, dry, and finely powdered. It should be supplied and kept sealed up in air-tight tins until required for use, as otherwise it will rapidly deteriorate by exposure to the atmosphere, and become useless.

Lime Tanks.—In ordinary practice a lime-mixing tank is fitted in connection with the main feed delivery system, and about 2 lbs. of lime per day are introduced into each boiler in use. It will be advantageous that the lime, before being placed in the tank, should be well mixed with water; it should then present the appearance of milk, with no solid particles in suspension in the water; it should be introduced into the mixing tank in small quantities at frequent and regular intervals, continuously rather than intermittently.

Alkalinity of Boiler-water.—In order to properly fix the amount of lime required, the boiler-water must be frequently tested both for alkalinity and for density, and it is desirable to maintain the water in the boilers in a slightly alkaline state, due regard being paid to the fact that, if too much lime be introduced, it will be deposited upon the inner surfaces of the generator tubes and lessen their heating efficiency.

Sea-water.—If sea-water should be introduced into the boilers, it will be necessary to work them at a higher water level and to force them, in order to increase the circulation of the water and prevent, as far as possible, the deposit of salt on the inner surfaces of the generator tubes. It will also be necessary to test the density frequently and to keep it as low as possible by blowing out. The quantity of lime should also be increased to prevent corrosion.

Leaky Condensers.—In order to prevent the admixture of salt-water with the feed-water, it is absolutely necessary to keep the condensers tight, and to this end they should be tested frequently when the vessel is in harbour. Salt-water not only produces corrosion in the boilers, but also makes deposits which are difficult to remove, and may possibly cause the tubes to be choked and burnt.

In ships fitted with twin screws, if it is found that the density of the boiler-water is rising rapidly and cannot, by means of blowing off, be kept as low as 15° to 20°, it may be advisable, in order to prevent choking, burning, or bursting of boiler tubes, to stop one set of engines, shut off the leaky condenser, and repair it at sea. This is the more important if the condensers show defects during a long voyage.

Density of Feed-water.—The purity of the feed-water can be tested by the nitrate of silver test occasionally, and by the hydrometer; and it should be an easy matter to locate the cause of any impurity which may exist. If the condenser tubes are leaking to any extent, the density of the water in the boilers will rapidly rise. Owing to the small amount of water contained in a Belleville boiler and its rapid rate of evaporation, much more danger exists of damage to the boilers from this cause than to the cylindrical type of boilers. The density should, therefore, be carefully and constantly recorded.

Feed Regulators.—The spindles of the feed-regulator valves must be kept clean and dry; they should receive attention two or three times in each watch, and the valve lever should be pulled and tested occasionally to see that the valve is free and the regulator in an efficient condition. The covers of the feed regulators, when not in use, should be removed occasionally to clean any deposit out of the bottoms of the feed float-boxes

A blow-off cock is fitted to this cover to allow the float-box to be blown out when in use. If the feed regulator should get out of order, it will be necessary to wedge up the top lever to keep the automatic feed valve open, and to regulate the feed supply by the graduated feed-check cock or valve.

Fluctuations and Water Level.—It will be found that the level of the water in the gauge-glasses falls whenever the furnace doors or smoke-box doors are opened, because the rates of combustion or evaporation become lessened owing to the introduction of cold air into the furnaces and the generator tube nests, in which case the feed regulator will come into operation and the desired height of water will be automatically obtained.

If it happens that the water level in the boilers is becoming gradually higher, after some considerable use of the automatic feed apparatus, it will generally be found that either the automatic feed valves have become worn and need refitting, or that the feed float is leaking through the joint of the top rod.

Shortness of Water in Boilers.—As long as water is visible in the gauge-glasses, the boilers may be relied upon to generate steam safely, but, should it become too low, warning will generally be given by the melting and blowing out of the bottom rows of fusible plugs. If the water disappears from the bottom gauge-cock on the float-box, the ashpit doors should be immediately closed to check generation of steam. All furnace and smoke-box doors should also be shut, and the generator tubes should be examined through the sight-holes of the smoke-box doors to ascertain whether they are red and overheated. If the tubes are black and there are no signs of overheating, the cause of the low water level may be due to some obstruction or defect of the feed system; but, if this cannot be at once discovered and remedied, the fires should be pushed back off the grate and the boiler shut off and allowed to cool down, the feed check valve being allowed to remain open. If, however, the tubes are red, the feed check valve should be shut off to prevent a subsequent flow of feed-water starting leaks in the screwed joints, &c., of the tubes; all smoke-box, furnace, and ashpit doors should be tightly closed and the fires allowed to die out, the pressure in the boilers being eased off by the safety valves as found necessary.

Fusible Plugs.—Small fusible plugs, made of lead, are inserted in the front junction boxes of the third row of tubes from the bottom of the elements and also in the front upper boxes of all elements. These plugs are made slightly taper and are about 1¼ inches long, their greatest diameter being about $\frac{3}{16}$ of an inch. The holes in the junction boxes which receive the plugs are tapped with a taper tap. The plugs are inserted by a special tool. Experience shows that it is best to anticipate the natural decay of the lead plugs and to renew them about every six months, on such occasions as the opening of a boiler for examination and cleaning.

The object of fitting the plugs is to give warning of the overheating of a tube due to shortness of water, and thereby to admit of precautions being taken which will prevent damage to the boilers.

The plugs can be renewed whilst steam is up, a special tool being supplied for the purpose. Plugs are said to be more durable if made of solid drawn wire; special presses are supplied for the manufacture of the plugs.

An unduly low water level may cause a plug to melt, or it may occasionally blow out from imperfect fitting or decay. If the water level be found to be too low, the boilers should be shut off, as explained in the preceding paragraphs. If the water level is not too low and a plug blows, it will be noticed that a jet of steam and water mixed, or of water only, will issue from the plug-hole; if the water is too low, an escape of steam only will take place. In any case, before opening a smoke-box door to replace a plug, it is necessary to examine the generator tubes through the sight-holes. If overheating has been the cause of the blowing of the plug, the tubes will be either red or the soot deposited on them will be burning. If there are no signs of overheating and there is no doubt about the water level of the boilers, the smoke-box door can be opened and a new plug inserted by the plugging tool.

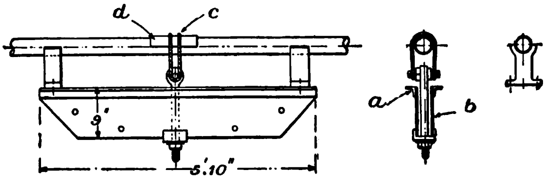

Fig. 108.

a, 2″ × 2″ × $\frac{5}{16}$″, angle steel.
b, $\frac{3}{8}$″ plate, steel.
c, a steel-wire rope, $1\frac{1}{2}$″ in circum.
d, a copper plate.

Tubes.—It is found that the lower rows of the generator tubes become bent, sometimes upwards and sometimes downwards. A slight bend is not of much importance; but, if the distortion is excessive, the tubes should be straightened by the special apparatus provided for the purpose, as shown in Fig. 108, or, if this is not available, by improvising a similar arrangement: supporting the ends of the tubes in order to prevent injury to the screwed joints at the junction-boxes, and pulling them down in the middle by a stretching screw; or jacking them up if bent downwards. The cone joint at the bottom of the elements is made water-tight by using nickel washers between the junction-box and the nipple of the feed collectors. If the bottom tubes are bent, there will be a tendency for the nickel joint to leak or break. It is usual to place two nickels, one over the other, between the coned surface of the bottom junction-box and the nipple of the feed collector.

Examinations.—The interiors of the economiser and generator tubes must be examined occasionally, as deposits accumulate in their lower portions, and, if not removed, will cause corrosion, overheating, and possibly burning. Special steel ribbon brushes are provided for cleaning out the interiors of the tubes, and zinc angle bars and strips are also supplied for insertion in the economiser tubes with a view to the prevention of corrosion. These zinc angles and strips require occasional cleaning, and should be renewed when worn.

Cleaning Interiors of Tubes.—When a boiler is opened for the purpose of cleaning out the deposits from the interior of the economiser and generator tubes and from the feed collectors and sediment-boxes, it will be found to expedite the process of cleaning should there be a deposit of any thickness on the tubes, if the boilers are emptied gradually, one row of tubes horizontally at a time; the scale or deposit is then kept in a moist state and is more easily removed than if it is allowed to dry and harden on the inner surfaces of the tubes, as would be the case should the boilers be opened out thoroughly and dried before the process of cleaning out the tubes has been commenced.

It should be remembered that, the cleaner the tubes are kept, the better will be the steam generation and coal economy, and the less the risk of bending the tubes.

Washing out Tubes.—Before closing up boilers after the tubes have been cleaned and brushed through, it is beneficial to wash them through from top to bottom of the elements with fresh water, if it can be procured, in order that all deposits of dirt and scale may be removed, and to ensure that no obstructions exist in the elements. The tubes should be thoroughly inspected by passing an electric lamp, specially supplied for the purpose, through them to ascertain whether any corrosion exists and that they are properly clean.

Smoke-box Doors and Casings of Boilers.—The smoke-box doors are made air-tight by means of a soft asbestos cord held in a groove, which envelops the whole of the front portions of the economiser and generator element boxes. When the smoke-box doors are closed, the clips on the doors press the surfaces at their edges tightly on to the asbestos cord, and so prevent the entry of air which would spoil the draught. The asbestos cord becomes hard in time, and will require renewal.

An examination should be made after every steaming of all smoke-box doors and of all doors either on the inner or outer casings of the boilers or uptakes; the casings themselves should also be examined in order to ascertain whether any air-leaks occur in the doors or joints, any of which should, if possible, be made good before the boilers are again used. It is also necessary that the smoke-box doors, casing doors, casings, and the furnace and ashpit doors of all boilers not alight, but which are connected to the funnels of boilers that are alight, should be air-tight. Any neglect of these precautions will not only check the draught in the boilers that are alight, but will, by admitting air into these boilers above the generator tubes, cause combustion to take place at the base of the funnel and in the upper portions of the boiler casings, thus causing flaming at the tops of the funnels, destruction of inner casings, difficulty in keeping steam, and excessive fuel consumption.

Brickwork.—After a voyage, and when the uptakes and tubes of the boilers have been brushed down and cleaned, an opportunity should generally be found for cleaning out the air channels in the back brickwork of the furnaces, and of repairing any defective brickwork. Attention should also be given to the backs of the boilers, and any soot or scoriæ which may be found lodging at the backs between the junction boxes and the boiler casings should be removed by scrapers made for the purpose, as otherwise such accumulations may cause damage to the back casing, or, in course of time, harden at the backs and so prevent the generator tubes from expanding in that direction where steam is being raised, thus causing bending of the tubes, distortion of the feed collectors and probable leaks at the nickel joints of the bottom boxes of the elements, and also a tendency to pull the elements off the rollers which support them at the back. Fig. 109 shows, on the left, the position taken up by a dropped tube, and, on the right, a special cast-iron chock fitted to support the tube when it slides forward.

Flap Valves in Downcomers.—The flap valves situated at the top of the sediment-boxes near their junctions with the "downcomer" tubes should always work freely; if they are allowed to "set up" they may possibly either wholly or partly close the downcomer orifice and so prevent a proper water supply to the elements. These valves must be overhauled frequently; the bottoms of the sediment-boxes should also be opened out and cleared at the same time.

Asbestos Rings.—The tube-box doors are jointed with asbestos rings of good quality, usually of three thicknesses of wire-woven asbestos sheeting; if the rings are of inferior quality they invariably leak. As a rule, even the best quality rings cannot be used over again, and new rings must be fitted when the doors are being rejointed.

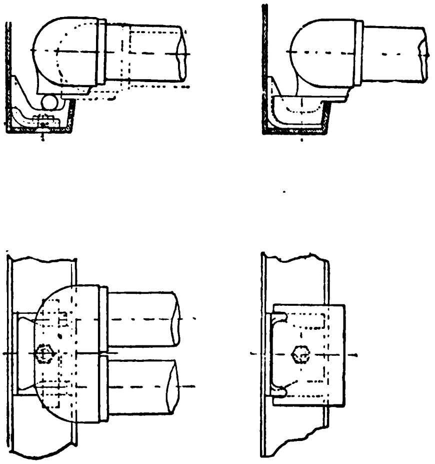

Fig. 109.

In obtaining asbestos rings, care should be taken to see that they fit tightly around the spigots of the doors. If they fit loosely there is a probability that they will be pressed out and off the faces of the door joints when the doors are being tightened up, and, consequently, the doors will leak as soon as they are subjected to the boiler pressure. In preparing templates for these rings it will, therefore, be an advantage if the dimensions are slightly smaller than the actual measurements of the spigots of the doors, so that the rings may be stretched on in place. The rings should be made without any joints in the material, and are now manufactured in this manner.

Water Test.—After closing up boilers it is advisable before raising steam to fill the boilers full of water and apply a pressure equivalent to the safety-valve load, by the feed pumps; this will give an opportunity of discovering and remarking any leaky door joints before the boilers are actually required for use.

Preservation of Boilers.—When boilers are not required for use they are best preserved by keeping them quite full of water at a slight pressure, say 5 lbs. per square inch; they should be pumped up directly after steaming, so that any air that may be contained in the feed-water will become heated and will escape from the boiler through the air cock at the top of the steam collectors. In all cases the water in the boilers should be maintained in a slightly alkaline condition, and lime in solution should, therefore, be supplied with the feed-water when filling up the boilers in the same manner as explained previously in this chapter.

If it is desired to keep the boilers full of water and out of use for a considerable time, it should be ascertained at least twice a week that the water has not leaked away from the boilers; the air cocks should then again be opened, and the feed pumps applied until it is certain that the boilers are again quite full.

If it is not practicable to keep the boilers quite full of water, for instance if they are required to be kept empty for repairs or examinations, they should be thoroughly dried out as soon as possible after being opened and cleaned.

Boilers.—Boilers should never be allowed to remain for any length of time only partly full of water; such treatment will leave a portion of the tubes exposed to damp and corrosion in their interiors. Airing stoves, placed in the furnaces underneath the generator tubes, should be used for the purpose of drying the boilers and also for keeping them dry afterwards.

Packing.—A special kind of packing, composed of granular white metal, mixed with mineral grease and plumbago, is used for the glands of the spindles of the automatic feed valves, and also for those of the steam stop valves. It is known as "Belleville anti-friction packing," and is supplied in two varieties—viz., fine and coarse—either in tins, or enclosed in a skin of woven cotton, in which latter case it is known as "sausage packing" from its shape. The sausage packing is supplied in various sizes and diameters to suit any glands, and is composed either of the fine or the coarse varieties, or of a mixture of them.

Vulcanite Rings.—Special vulcanite rings of various sizes are also supplied with this packing; the object of the vulcanite ring being to fit tightly around the rods at the top and bottom of the stuffing-boxes of the glands, and so prevent the particles of Belleville packing from being squeezed through. In order to ensure successful working, too much care cannot be given to the accuracy of fit of these vulcanite rings around rods or spindles. In the piston-rod and slide-rod glands of small engines and in steam stop-valve glands, if vulcanite rings are not available, a tightly-fitting turn of asbestos packing at the top and bottom of the glands is an efficient substitute for the vulcanite rings, but the latter appear to be absolutely necessary in the stuffing-boxes of the automatic feed valves, also in those of the reducing valve spindles of the main engines.

Belleville Packing Substitutes.—Of late years a substitute for Belleville anti-friction packing has been manufactured by the Admiralty Authorities and by Naval Engineer Officers themselves, which gives as good results as the Belleville packing.

This packing is manufactured as follows:—Lead is melted and poured through a wire-gauze sieve of 40 mesh held 1 inch or so above a pan of water. The globules so formed are sifted to separate those above $\frac{1}{8}$ inch in diameter, the larger of the globules left are separated by rocking in a trough containing water, and are then mixed half and half with those above $\frac{1}{8}$ inch in diameter. A greasy paste is made, consisting of 1 part black lead to 1 part of mineral oil by bulk, and this paste is mixed with the lead globules in the proportion of 10 parts of metal to 1 part of greasy paste. The packing so formed is then filled into convenient sized cylindrical casings made of canvas.

Gauge Glasses.—These fittings gave considerable trouble in the earlier types of Belleville boilers, as the glass tubes used broke frequently, until an improvement was made in the method of packing them, which has practically overcome the original difficulties. They are now packed with specially made hexagonal washers composed of a mixture of asbestos fibre, mineral grease, and black lead. A closely-fitting india-rubber ring is enclosed at each end of the gauge-glass tube between two of these hexagonal washers, and the whole is screwed up by the nuts at the top and bottom of the gauge mounting, the nuts being just "hand taut" when screwed down to their final position.

Gauges made of talc were tried as a substitute for the glass tubes, but the talc became laminated and opaque, and was discarded. It is now the usual practice to fit one of the water gauges with a glass tube, and the other water gauge on each boiler with a window-frame mounting, and this arrangement has proved satisfactory.

With the view of affording assistance to officers concerned in the management and working of Babcock & Wilcox, Niclausse, and Yarrow boilers, my Lords Commissioners of the Admiralty are pleased to direct the following instructions to be issued:—

Babcock & Wilcox Boilers[*]—*Raising Steam.*—The boilers should always be filled with clean fresh water, or distilled water, and steam should be raised slowly when the brickwork is new; at other times, if the service require it, steam can be raised as quickly as the fires can be got to work.

Whilst the boilers are being heated, attention should be devoted to all the boiler fittings and feed arrangements, to see that they are in good working order, and special care should be exercised in tightening up again, with the special spanner provided for the purpose, any handhole fittings that may have been taken off for examination or cleaning.

After steam is raised, the boilers should be connected up with care, and the main stop valves opened very slowly; the opening of the stop valves to be just to that extent which shall give a small amount of wire drawing to the steam, but not to contract the area of opening sufficiently to cause any considerable loss of pressure between the boiler and the engines.

Firing.—To maintain a steady steam pressure and ensure economical working, it is necessary to fire at equal intervals of time, the method usually adopted being to number the fire-doors as per sketch and to fire through each opening in order of numbers at equal intervals.

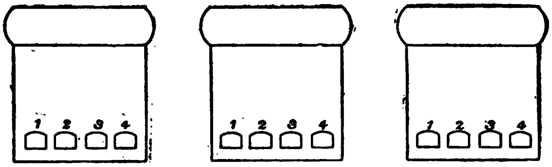

Fig. 110.

As a rough guide of what should be done, it has been found that for maximum continuous steaming with good Welsh coal, from three to four good shovelsful at a time should be thrown through one fire-door opening on each boiler every two and a half minutes. The number "One" fires of all the boilers to be fired in rapid succession one after the other, one door only to be open at a time—two and a half minutes afterwards the number "Two" fires in all the boilers to be fired in rapid succession; two and a half minutes after that, the number "Three" openings, and so on. This may be conveniently arranged with a clock in each firing-room—each clock set a little in advance of the other, so as to have as few fire-doors as possible open at one time.

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[*] See the Admiralty circular letter of 25th July, 1904.

If a higher rate of steaming is required, it is preferable to decrease the interval between firing, rather than add largely to the quantity of coal put on at a time.

For ordinary service the number of boilers in use should be arranged for at a rate of combustion of from about 15 to 18 lbs. of coal per square foot of fire-grate per hour, with fires from 4 to 5 inches thick, and no air-pressure in the stokehold. With an air-pressure in the stokehold of half-an-inch of water, the fires should be from 6 to 7 inches thick.

The fires should be kept free of the dead-plates, so that the furnace door baffles shall not become over-heated. The amount of opening of the ashpit doors should be kept as small as possible, and great attention should be paid to this point, as the best results are obtained with an excess draught checked at the ashpit.

The coal must be well broken up and thrown on the fires quickly, the largest lump being not greater than a ball of 4 inches diameter. The furnace doors should not be left open longer than is necessary, so as to prevent too much cold air getting into the furnaces. Two men should be employed for the operation of firing; one to put the coal on, and the other to open and close the furnace door in the intervals between separate shovelsful. When a furnace door is opened for firing, the stoker should see at a glance where coal is required, for the flame and smoke caused by the first shovelful, as soon as it is thrown in, prevents the exact condition of the fire from being afterwards seen. A sharp look-out should be kept for any thinning of the fires at the sides and between the furnace doors, and, in order to prevent this, the fire near the brickwork should be kept rather thicker than that of the remaining area. The stoker should learn to distribute the coal over the grate so uniformly with the shovel that it will be unnecessary to level the surface with the rake or slice. A rake has only to be used when a fire has become too thick on one part of the grate and too thin on another.

Under natural-draught conditions of steaming, the same amount of coal should be burnt in each furnace, and, as it frequently happens that some furnaces have a better draught than others, the draught plates should be regulated accordingly. In order to maintain fires of uniform thickness under forced draught, fires which get greater draught should be supplied with more coal in order to keep them of even thickness and free from holes; the maintenance of a steady output of steam under forced draught should be effected by the speed of the fans and not by the ashpit draught plates.

The ashes in the ashpits should be removed as often as convenient, as they interfere with the draught and injure the fire-bars.

It is important for the most effective combustion and economy that the fires should be kept light and level, thus enabling the combustion to take place in the fire-box itself, preventing as far as possible the sooting-up of the tubes and flaming in the uptakes and funnels.

Cleaning the Fires.—When steaming at powers exceeding 60 per cent. of the full power, only half the grate surface of a boiler should be cleaned at a time, the fires of the other boilers being forced more heavily if necessary. The fire on half a grate should be burnt down, clinkered, and re-charged. When the fire on this half has again become bright, the other half should be cleaned in the same way.

For the development of powers below 60 per cent. of the full power, the number of boilers in use should be sufficient, with an average rate of combustion of about 20 lbs. of coal per square foot of fire-grate, to allow of one boiler at a time being burnt down for cleaning purposes.

At all rates of combustion the fire-bars must be kept free from clinker by the frequent use of the slice in the intervals between the cleanings of the fires.

Feeding.—The feeding must be done uniformly, and not irregularly.

When getting under way, commence by opening all the feed check valves a little and to the same extent, also try through all the water gauges.

Should it so happen that the feed-water ceases to flow for a short while owing to the pump ceasing to feed, the combustion should at once be checked by closing the ashpit doors and immediate steps taken to put on the auxiliary supply.

Steps should also be taken to ascertain by working the float lever that the regulator is not at fault.

Water Level.—The water level should be kept between ¼ and ⅜ glass when under way; when the boiler has the ashpit doors shut, and is doing no work, about 2 inches in the glass is sufficient.

The handle of the automatic feed regulator should be moved about once a day so as to ascertain whether the float is working freely, and, at least every three months, the float lever and piston of the automatic feed apparatus should be taken out, examined, and cleaned.

Automatic Feed Regulator.—All the boilers are fitted with an automatic feed regulator composed of a revolving piston valve actuated by a float, and controlling the feed supply, the object of the apparatus being to automatically control the admission of feed-water to the steam generator.

With the Babcock & Wilcox feed regulator, the working water level of the boiler may be adjusted by moving the piston valve lengthways, by an adjusting screw in accordance with an index, which is attached to the screw itself. By this operation, owing to the ports being cut diagonally both in the piston valve and liner, the position of the cut-off is altered; there is also a handle attached to the regulator, by which the free movement of the float can be ascertained.

As the regulators are only intended to level the feed-water when the boilers are at work, it is necessary, when the boilers are shut off, to close the feed supply by using the hand check valves.

Feed-water Temperature.—The temperature of feed-water leaving the main condensers should not be allowed to fall below 120° while fairly under way, and for the auxiliary condenser a slightly higher temperature will be beneficial; this will not only tend to economy, but prevent the absorption of so much air by the water, thus promoting the preservation of boilers and pipes.

Blowing Down and Scumming.—When under steam and the water in the boilers is fresh, they should be blown down once a watch; for this purpose the blow-off cock on the mud drum should be opened wide and quickly for about two seconds, and then closed quickly. After waiting about one minute, this operation should be performed a second time. This removes the oil and lime deposited in the mud drum.

Never open the blow-off a small amount for a long time, in order to blow out, as this procedure may choke up the valve or cut the faces and cause leakage.

If the gauge glasses show that oil is present in the steam drum, the scum cocks should be used occasionally.

Steaming at High Power—(1) *With Natural Draught.*—When the order for full speed is received, open the ashpit doors and back dampers, charge the grates more frequently, but at regular intervals and using an equal amount of fuel at every charge; the amount to be such as shall keep the layer of the fire on the grate quite uniform and not more than 5 inches thick.

If necessary, equalise the layer of fuel with the fork or rake after three or four *complete charges of the whole grate surface.*

If the fires become too dirty, raise the clinker with the slice, and remove it quickly.

To resume the ordinary speed, it will be sufficient to reduce the opening of the ashpit doors, and to increase the interval between the firings.

(2) *With Assisted Draught.*—When the natural draught is not sufficient, the fans should be started, either to assist the natural draught with an open stokehold or, if required, with the stokehold closed.

Action to be Taken if the Engines are Suddenly Stopped.—If the steam requirements are suddenly greatly diminished or altogether stopped, the rate of combustion must also be diminished; to do this, close all back dampers and ashpit doors, and, if this is not sufficient, slightly open the furnace doors. The action of opening the furnace doors, however, must be done gradually, to prevent any too sudden cooling of the heating surfaces, and should not be resorted to unless absolutely necessary.

A further decrease in the production of steam can be brought about by increasing the feed, but it must not be overlooked that, when the engines are again started, the water level will tend to rise, so that the boilers must not be allowed to get too full.

Filters.—Care should be taken that the filters for filtering the feed-water are kept in good order and clean, for, if the cloths are allowed to clog, grease will pass through and obtain access to the tubes.

Cleaning the Fire Side of the Tubes under Steam.—If water is not used in the ashpits, it will only be necessary to clean the fire sides of the tubes under way on long runs; for instance, after three or four days' continuous steaming at 60 per cent. of the full power.

The tubes can be cleaned by a steam or air lance while the boiler is at work, or, in some Babcock & Wilcox boilers, by a fixed apparatus. The lance is inserted between the tubes through the doors at the sides of the casings, but in some boilers it is used between the headers from the fire-door end.

Cleaning by means of steam or air lances should only be done when the fires are actively at work, and then care should be taken that the lance is well blown through before it is applied to the tubes; if this precaution is not taken, the soot on the tubes will be wetted and will cake.

Scoriæ which accumulate on the bottom row of tubes can be removed, as far as practicable, by scrapers when the fires are being cleaned.

Corrosion.—To preserve the boiler from corrosion, the water therein contained should always—whether at rest or working—be kept alkaline by the introduction of lime.

Lime partially amalgamates with any oil present, thus facilitating the deposition of grease either in the filters or feed tanks. Great discretion, however, should be exercised in the amount of lime used. So far as possible, only lime in solution should be allowed to enter the boilers, as the solid particles increase the amount of deposit in the tubes.

Shutting Off a Boiler.—When a boiler is to be shut off, all accumulations of dirt should first be removed by use of the blow-out valves, and the boiler should then be pumped up again to the usual level, unless it is to be emptied to carry out any repairs.

If the boiler is to be out of use for some time, it should be pumped full for preservation.

Meantime the fire is allowed to burn down slowly, so that the circulation in the boiler may be kept up as long as possible to prevent any dirt still remaining in the water from settling in the lower tubes.

After the fires have been drawn, the grates and brickwork of the furnaces should be thoroughly cleaned, the ashes should then be drawn, and the ashpans emptied of water, and cleaned. Blowing out the boilers should not be resorted to as a general practice.

Regular Inspection.—Whenever a boiler is put out of use, an external inspection of the lowest rows of tubes and of the brickwork in the furnace should be made.

Defective places in the brickwork should be repaired as soon as possible, and special care should always be taken that the protective arches over the furnace doors are kept in good condition.

The curvature of the lower tubes should be frequently observed. A curvature of ¾ inch is almost always a sign of either internal fouling sufficient to interfere with the proper conduction of heat, or the presence of oil which, although perhaps only sufficient to form a very thin layer over the inner surface of the tubes, may be quite enough to cause a considerable curvature to take place. It is usually desirable to consider the removal of the tube should a curvature of 1 inch be exceeded.

Under such circumstances, immediate cleaning of the interior of the tubes is necessary.

The ends of the lower tubes should be carefully examined for signs of leakage, and if any such signs appear they should be at once investigated and any defect remedied. Should the leakage be sufficient to necessitate rolling, the tube rollers should be used as lightly as possible.

The soundness of the whole lagging on the boilers should be examined, and any loose plates repaired. Special care should be taken that the casing doors fit well on their framing and the snecks for securing them act efficiently, also that the asbestos packing between the headers is in good condition, thus preventing any excess of cold air entering the boilers and causing a loss of draught and efficiency.

Preservation of the Boiler.—The boiler when not under steam, or open for examination, is to be kept quite full with fresh water, the boiler being pumped up within twenty-four hours of completion of steaming, and so kept to within twenty-four hours of again being so required.

If the boiler is to be examined within a few days after completion of steaming, the water should not be allowed to remain at working height, but the boiler should be pumped up as directed above.

When it is necessary to open out the boiler for examination, it should be emptied and carefully dried to prevent corrosion, and kept dry by means of airing stoves alight in the furnaces.

In pumping up boilers, care should be taken to ensure the water being distinctly alkaline, by adding an additional quantity of lime to the feed-water previous to pumping up.

Specal attention should be paid to ensure that boilers at W.W. are kept quite full.

The shrinkage of the water by cooling, or any loss by leakage, is to be made up by the hand-pump daily until it is certain, by reason of water issuing from the air cock on the highest part of the boiler at the first stroke of the pump, that the boiler is quite full. Any subsequent loss of water is to be made up once a week.

As a rule, the outer surfaces of the tubes are galvanised and so protected from rusting. It is desirable, in cases where the zinc coating has been burnt off the lower tubes, to protect the surfaces exposed to the flame by a coating of blacklead and water. This coating will not only protect the surfaces of the tubes, but will also prevent ash and clinker forming on them.

Funnels which are not in use are to be kept covered.

In cold weather the temperature of boiler-rooms, and of water in boilers which are quite full, must not fall below 40° F.

In commissioned ships, all the boilers are to be thoroughly examined internally and externally once in each quarter, even though steam has not been raised since the date of the last examination. It is important that the connections of the zinc protectors be kept efficient.

Internal Cleaning.—The two lower rows of tubes should be cleaned as frequently as possible, the upper rows at varying intervals, the length of which is to be determined on examining the boilers from time to time.

Should the sediment in the lower tubes be of a soft nature, it can be removed by means of the stiff wire brushes which are supplied. If the brushes are not capable of removing the scale, the hand pushing scrapers should be used.

If scale of a nature requiring the use of the turbine, or other suitable cleaner, be found in the tubes, its removal will be facilitated by first boiling out with a strong solution of soda, which will have the effect of softening the scale; the formation of such a scale, however, can only be caused by abnormal conditions.

To do this, allow 1 lb. of soda for every 30 square feet of heating surface, and boil for at least twelve hours, allowing the steam to blow off through the safety valves at about 40 lbs. pressure; the water level while boiling out should be about 1 inch above the scum pan. Every two hours an inch of water in the gauge should be blown out through the scum cocks, which should be kept wide open until the steam blows through. The bottom blow-off cocks should also be opened wide for about 10 seconds after the scum cocks are shut off and the water has regained its normal level, the loss to be made up with fresh water.

After the boiling out is finished, draw the fires, and let the boiler cool down; when sufficiently cooled, lower the water in the boiler until the steam collector is empty, and clean that part thoroughly. Then lower the water in the tubes gradually; take off the caps from the front and back headers, and clean the tubes out thoroughly whilst the deposit is in a wet state. Clean each row of tubes successively in the same manner, working downwards until all are finished; then take the hand-hole fittings off the sediment-box and the auxiliary sediment-boxes, and clean these likewise. All the short tubes connecting the headers to the steam collector and to the sediment-box are to be cleaned. The headers are to be thoroughly cleaned before any tube doors are replaced.

Any grease or other deposit collected on the walls of the steam collectors is to be removed as soon as observed.

It is important that the external parts of boilers which are not under steam be kept dry and clean.

After the boiler has been closed up, and before steam is raised in it, it is to be tested by water pressure to at least nearly the pressure at which the safety valves are loaded, and all the joints inspected for leakage during the time the pressure is on. When steam is being raised in the boiler, the door fittings are to be tightened as requisite with the special spanner provided; the steam pressure being on the back of the door tends to slacken the nuts, and if this precaution be not taken, some of the joints may show a tendency to leak.

Partial internal inspection, the extent of which will depend upon the circumstances of the case, is to be made whenever a boiler is put out of use after a period of steaming, and on other occasions as opportunities offer.

For a partial examination, it is only necessary to remove the tube hole doors from the two bottom rows of tubes, and to examine these tubes; if they are in a satisfactory condition as regards corrosive action and deposit, it is probable that the tubes of the upper rows are also in a satisfactory condition, and it will, in general, be sufficient to test this by inspecting only one tube in each row taken diagonally across the boiler.

No boiler is to be closed up until every tube, which has been opened out, has been searched, and the other parts of the boiler carefully examined by an engineer officer, or by a trustworthy and competent chief petty officer.

On all occasions after steaming, in order to get rid, as far as practicable, of any grease or sediment before the fires are drawn, water is to be blown out through the scum cocks until steam blows through, and the bottom blow-off cocks are also to be opened for a short time. All the tubes are to be thoroughly cleaned externally with brushes, as soon as practicable, after the fires are out. The fire side of the lowest row of tubes, and the furnace brickwork are to be carefully examined. The ashpans and bilges under them are to be thoroughly dried out.

Repairs.—It is very important that the brickwork should be kept in good condition, otherwise the casings will suffer.

A bottom tube can be taken out by cutting a groove in each end with a cross-cut chisel, taking care not to damage the tube seats. Also cut the tube in the centre from the furnace, with a special cutter supplied for that purpose; then, after closing in the ends of the tube, drift each half out separately.

Should it become necessary, for any reason, to remove an upper tube, this can be easily done by closing the ends with a cupping and withdrawing tool supplied for that purpose, and at the same time driving the tube out. This operation does not necessitate cutting the tube in any way, and can be carried out very quickly.

Handhole and Manhole Doors.—The manhole doors in the steam and water drum, and the handhole doors on headers and mud drums, are jointed with wire-woven asbestos rings, which should be blackleaded on one side only—*i.e.*, the side next the header. The surfaces of the headers should be cleaned before the handhole covers are put on.

It is very important, after renewing a number of handhole joints, that they be screwed up again while steam is being raised, as the pressure on the inside tends to make the nuts slack, and thus causes the joints to leak.

The screwing up of these doors should be done by one man only, and with the special spanner provided for the purpose, so that no more than the necessary and uniform strain may be applied.

Under no circumstances should any greater leverage than these spanners themselves provide be applied.

Banking Fires.—As a general rule, fires should be allowed to burn out when the engines are stopped, unless steam is likely to be required at very short notice.

The banking of heavy fires is undesirable, for, with closed furnace and ashpit doors, it is liable to cause overheating and bending of the fire-bars and bearer-bars.

When it is considered essential to bank fires, they should be pushed to the back of the grate and kept light.

The boilers should be allowed to cool down gradually, and the fire-doors and ashpit doors kept shut.

Niclausse Boilers*—*Raising Steam.*—The boilers should always be filled with clean fresh water or distilled water, and steam should be raised slowly when the brickwork is new; at other times, if the service require it, steam can be raised as quickly as the fires can be got to work.

Fires should be kept as thin as possible, and without holes, while raising steam and until the engines are well under way; this will guard against steam blowing off, and will also prevent the fire-bars from becoming warped and burnt, by the complete closing of the ashpit doors, with clean and heavy fires.

In opening the stop valves of a group, or groups, of boilers, the amount of opening should vary according to the distance of the boilers from the engines, those farthest from the engines being opened the most; the total amount of opening in all cases is to be only sufficient to supply the engines with the required quantity of steam.

The lifting gear of the safety valves is to be examined and the valves are to be moved off their seats before fires are lighted. After steam has been raised, the safety valves should not be moved by hand unless they are leaking, or in circumstances which necessitate the reduction of steam pressure in the boilers.

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* See Admiralty Circular Letter of 21st June, 1904.

The water gauges, steam gauges, and all other boiler fittings are to be examined and tested during the time steam is being raised.

Management of the Fires.—This should be carefully considered, as it governs the economical use of fuel and the efficiency of the boiler.

Trials made with apparatus having a certain number of boilers in use have shown that the management of the fires, and the frequency and amount of the firing, should not be left to the discretion of the stokers, to avoid the grates being unequally charged—some nearly empty and others too heavily loaded. In either case bad combustion is the result.

A too heavily loaded grate gives the worst results, for, as there is not a sufficient quantity of air, the fuel distils on the grate, and the gas produced ignites on combining with the air, causing either flaming in the funnels or overheating of the uptakes.

To keep a suitable thickness of fuel on the grates—that is, from 4 to 5 inches—it is necessary to adopt a systematic method of stoking.

Systematic Stoking.—When there are several boilers distributed in different stokeholds, it is necessary to lay down rules for stoking, the object being to ensure economical working, and, as far as possible, the same rate of evaporation in each of the boilers.

The two principal points to be considered are—(1) the frequency of the firing, and (2) the amount of coal supplied.

As regards the latter, about 28 lbs. may be adopted in practice for each charge.

This quantity corresponds to about two shovelsful when the ordinary-sized shovels are used.

Whatever the speed, the quantity decided on should not vary.

Consider the case of a vessel having four boilers in one stokehold, each boiler having two fire-doors, making, in all, eight doors. Even when combustion is active, with charges of 28 lbs. there will be considerable intervals between each firing. These intervals are absolutely necessary, in order that only one door may be open at a time. Again, supposing these furnaces to burn 30 lbs. per square foot of grate per hour, for the four boilers—having together 150 square feet of grate—4,500 lbs. of coal would be burned per hour, divided amongst eight fire-doors, which would give an interval of about three minutes between two consecutive firings by the same door.

The doors of the furnaces in question being numbered as directed, they should be fired in numerical order.

For this purpose, the leading stoker every three minutes calls out "one." Immediately the stoker of the first boiler throws on his two shovelsful through door No. 1; the stokers who have charge of doors 2, 3, and 4 fire them directly afterwards, one following the other, and are followed by 5, 6, 7, and 8, always in such a way that two doors are never open at the same time.

1st Boiler.		2nd Boiler.		3rd Boiler.		4th Boiler.	
1	5	2	6	3	7	4	8

If the number of boilers in one group is too great for all to be fired in the desired time, fire two doors at a time. For instance, in the above case 1 and 3, 2 and 4, 5 and 7, 6 and 8 would be opened together.

Working thus with several furnaces at the same time, the fires will be uniform.

For ordinary service, the number of boilers in use should be arranged for a rate of combustion of from about 15 to 18 lbs. of coal per square foot of fire-grate per hour, with fires from 4 to 5 inches thick, and no air pressure in the stokehold. With an air pressure in the stokehold of ½ inch of water, the fires should be from 6 to 7 inches thick.

Cinders should not be allowed to accumulate in the ashpits.

The number of revolutions, the horse-power, and the combustion of coal for different speeds being known, the combustion per square foot of grate can be deduced.

A table can then be made .with different numbers, each corresponding to one of these rates of combustion. Opposite each of these numbers will appear the interval between two consecutive charges by the same door according to the method pointed out above. At each change of speed the engineer officer of the watch will then only have to give a number corresponding to the speed desired, and, this order being given to all the stokers, the fires will immediately burn at the new rate. With this method it will be easy to maintain a uniform rate, however many fires are employed.

The following is a model table of stoking drawn up for a constant charge of three small shovelsful, equal to 33 lbs. and corresponding to various rates of combustion for a stokehold having eight doors, the surface of the grate being 150 square feet :—

Table of Stoking.—Constant amount of the charge = 33 lbs. or three shovelsful.

Stoking Numbers.	Interval between Firings.	Consumption of Coal per Hour.		
		Per Door.	Per Square Foot of Grate.	Per Boiler.
	Minutes.	Lbs.	Lbs.	Lbs.
1	11	180	9·7	360
2	10	198	10·5	396
3	9	220	11·7	440
4	8	246	13·1	492
5	7	282	14·9	564
6	6	330	17·6	660
7	5	396	21·1	792
8	4	495	26·5	990

The coal must be well broken up and thrown on the fires quickly, the largest lump being not greater than a ball of 4 inches diameter. The furnace doors should not be kept open longer than is necessary, so as to prevent too much cold air getting into the furnaces. Two men should be employed for the operation of firing—one to put the coal on and the other to open and close the furnace door in the intervals between separate shovelsful. When a furnace door is open for firing, the stoker should see at a glance where coal is required, for the flame and smoke caused by the first shovelful, as soon as it is thrown in, prevents the exact condition of the fire from being afterwards seen. A sharp lookout should be kept for any thinning of the fires at the sides of the grates and between the furnace doors, and, in order to prevent this, the fire near the brickwork should be kept rather thicker than that of the remaining area. The stoker should learn to distribute the coal over the grate so uniformly with the shovel that it will be unnecessary to level the surface with the rake or slice. A rake is only to be used when a fire has become too thick on one part of the grate and too thin on another.

As the fires are charged frequently, and in small quantities, the furnace doors must be kept open for a very short while each time.

All the doors should be kept carefully closed (the furnace and inspection doors as well as those of the ashpit) when stopping for a short time. Care must be taken not to leave too much fuel on the grate, as this might cause a rapid deterioration of the fire-bars.

In the case of a complete stoppage the fire should be pushed to the back of the grate or else extinguished. In the former case, care must be taken to cover the fire with moist cinders, and to shut the furnace doors and ashpit dampers quite close.

Flaming in the Uptakes and Funnels.—This will occur when the fires are too thick or very dirty; it can be stopped by slicing the clinker off the bars, by burning down thick fires, and by giving more air under and over the fire-bars.

Care must be taken to avoid having thick fires in some boilers and thin fires, or fires with holes in them, in other boilers leading to the same funnel, as in these circumstances coal is wastefully burnt, and flaming in the uptakes or funnels will almost inevitably occur.

Cleaning the Fires.—When steaming at powers exceeding 60 per cent. of the full power, only half the great surface of a boiler should be cleaned at a time, the fires of the other boilers being forced more heavily if necessary. The fire on half a grate should be burnt down, clinkered, and re-charged. When the fire on this half has again become bright, the other half should be cleaned in the same way.

For the development of powers below 60 per cent. of the full power, the number of boilers in use should be sufficient, with an average rate of combustion of about 20 lbs. of coal per square foot of fire-grate, to allow of one boiler at a time being burnt down for cleaning purposes.

At all rates of combustion the fire-bars must be kept free from clinker by the frequent use of the slice, in the intervals between the cleaning of the fires.

Feeding.—Fresh water only must be used for filling and feeding the boilers. Frequent tests should be made to ascertain that the water in the boilers is quite fresh. The feeding should be carried out as uniformly as possible. By watching the levels in the water gauges it can be seen if it is necessary to open or slightly close the feed check valve of any of the boilers. This should be done gradually, a variation of one-quarter of a turn ought generally to be sufficient to keep all the levels at the same height.

The normal water level is about 6 inches above the bottom of the gauge glass. This should be kept constant when steaming.

Should it happen from any cause that difficulty is experienced in obtaining a sufficient supply of feed-water and the level in the water gauge glass falls unduly, steps should be *immediately* taken to check the fires by closing the ashpit dampers and ceasing to fire up. Should the water entirely disappear from sight in the glass, the boiler stop valve should be closed, and the safety valves eased as necessary to reduce the pressure.

After the pressure has fallen below 50 lbs. the fires should be put out, unless the water again shows in the glass.

If the engines are suddenly stopped, steam should not be allowed to blow off through the safety valves; the steam production of the boilers should be checked by closing the ashpit doors, by increasing the feed, and by the careful use of the silent blow-off to the condenser.

It must not be overlooked that when the engines are again started the water level will rise in the boiler.

An automatic feed regulator composed of a balanced valve, actuated by a float, controls the feed supply. The float moves vertically in the steam drum and is attached by a lever to a horizontal spindle. This spindle turns on its own axis, and has at its other end another lever carrying a frame with a sliding nut, which can be moved up and down by hand by means of a screw with a milled head. This sliding nut has a projecting stud which engages in a hole in a lever at the end of a second spindle, placed in the same straight line as the first and connected at its further end with the balanced valve. By turning the screw from left to right the sliding nut moves down so as to shut the valve; the valve is opened by turning the screw in the opposite direction. A weight at the end of the lever containing the sliding nut counterbalances the various parts. This counterpoise should never be shifted after the apparatus has been adjusted.

As a general rule, the position of the counterpoise will have been determined in the workshop when the apparatus is set and regulated, but if this has not been done the feed regulator should be set up on any vessel in which the water level is the same as in the boiler. When adjusted, the lever bearing the counterpoise should be horizontal; if it is but slightly out, the difference can be made good by means of the sliding nut, but the latter should be about midway in its travel when the apparatus is regulated, so that the latter can be set by hand above or below the normal level, according to circumstances, if it is desired to vary the water level.

The feed regulator should be set up with the greatest care, and it ought to be possible to work all the moving parts without the slighest effort. The float should be fitted so as to move quite perpendicularly to the axis of the spindles which actuate the valve, and these spindles should be set up with sufficient play to permit the valve to move quite freely, and the stuffing-boxes should be no tighter than is absolutely necessary.

Management.—The management of the regulator is simple when it has been properly set, as indicated above. When the boiler produces either slightly more or slightly less than the normal amount of steam, nothing need be done to the regulator, but if the boiler produces, for a considerable time, very much less than the normal amount of steam, the inflow of water should be lessened by means of the feed check valve.

When the boiler is stopped under pressure for a considerable time, the feed check valve should be completely closed so as to prevent the level from rising, for the regulator cannot be considered as reliable for this purpose. The check valve should afterwards be opened a little, before the ship gets under way again.

To keep the Regulator in Repair.—It is easy to keep the regulator in good repair, because there are only two stuffing-boxes, the spindles of which have a slow movement. The packings of the stuffing-boxes should preferably be made with anti-friction sausage packing, or, if this is not procurable, with two turns of asbestos cord, about ¼ inch in diameter, well smeared with special anti-oxidising grease.

Care should be taken to well grease, from time to time, the sliding nut and its screw with the same preparation, in order to preserve them from oxidisation. The float should frequently be worked by hand, by means of the handle on the lever containing the sliding nut, so as to keep the apparatus quite sensitive.

In no case must any screw nut be tightened whilst the boiler is under pressure, not even those of the dogs that hold the tubes, or of the handholes, &c.

Blowing Down.—At least once a day, and more often if it is thought necessary, the boiler should be blown down. The level should be increased to about 2½ inches above the normal, and the scum blow-off cock on the steam drum should then be opened.

In order that the operation may be effectual, it should he continued until steam begins to pass through the scum cock. It will be easy to discover when this is happening by the noise produced by the passage of the steam in the blow-off pipe.

In this way any grease entering the boilers in the feed-water will be got rid of. The blow-off cocks at the bottom and also that on the feed-box (which is very important) should then be opened for a minute.

The scum and the lower cocks should be used as often as the nature of the water renders it necessary, and this should be specially determined.

The gauge cocks and the water-gauge stand pipe should be frequently tested when the boiler is under pressure, to see that they are in no way obstructed.

Preservation.—In order to preserve the boiler, it should be completely filled.

The shrinkage of water by cooling or any loss by leakage is to be made up by the hand pump daily until it is certain, by reason of water issuing from the air cock on the highest part of the boiler at the first stroke of the pump, that the boiler is quite full. Any subsequent loss of water is to be made up once a week.

Bogies or small fires are to be lighted in the ashpits when required, to keep the external parts of the boiler free from moisture, whether the boilers are preserved internally by the wet or by the dry process.

Funnels which are not in use are to be kept covered.

In cold weather, the temperature of the boiler-rooms and of water in the boilers which are quite full must not fall below 40° F.

In commissioned ships, all the boilers are to be thoroughly examined internally and externally once in six months, even though steam has not been raised since the date of the last examination. It is important that the connections of the zinc protectors be kept efficient.

Use of Lime.—The water in the boilers should be tested at least once in every watch, and sufficient lime added to neutralise the acids.

Cleaning Generally.—Partial internal inspection, the extent of which will depend upon the circumstances of the case, is to be made whenever a boiler is put out of use after a period of steaming, and on other occasions as opportunities offer.

For a partial examination, it is only necessary to remove the inner tubes of the two rows of tubes nearest the fire; if these outer tubes are in a satisfactory condition as regards corrosive action and deposit, it is probable that the tubes of the upper rows are also in a satisfactory condition, and it will, in general, be sufficient to test this by inspecting only one tube in each row taken diagonally across the boiler.

Boilers which are to be opened for thorough cleaning and examination are to be boiled out with a strong solution of common soda, either before fires are drawn or by lighting fires especially for the purpose. To do this, allow 1 lb. of soda for every 30 square feet of heating surface, and boil for at least twelve hours, allowing the steam to blow off through the safety valves at about 40 lbs. pressure; the water level while boiling out should be about 1 inch above the scum pan. Every two hours, an inch of water in the gauge should be blown out through the scum cocks connected with the scum pans; these cocks should be kept open until steam blows through. The bottom blow-off cocks should also be opened wide for about ten seconds after the scum cocks are shut off and the water has regained its normal level, the loss to be made up with fresh water.

After the boiling out is finished and the fires drawn, the headers should be blown out empty through the bottom blow-off cocks.

The boiler should not be emptied of water except when it is to be cleaned, for the deposits therein, if allowed to dry, will harden, and the advantage of the deposits in the inner tubes being in a muddy condition will be lost.

It must be taken as a general principle that the water should remain in each tube until the very moment that it is going to be cleaned.

To clean the inside of the boiler, the dog securing each pair of tubes must be removed, then the inner tube unscrewed by means of the special spanner which fits into the hollow head of this tube, turning it in the opposite direction to the hands of a clock.

As soon as the tube is taken out it should, if it contains any deposits, be washed or plunged into water, and, if necessary, cleaned with the metal tube-brush.

Care must be taken, immediately afterwards, to clean the thread at the front end of this tube and to smear it with special anti-oxidising grease.

If, as very rarely happens, the outer tube should turn whilst unscrewing the inner tube, the two tubes should be taken out together, the outer one placed in a metal collar made in two pieces, and held in a vice, and then the inner tube unscrewed with the spanner.

The outer tube itself must never be gripped in a vice, or it may be damaged.

After the inner tube has been taken out, it should be ascertained whether the outer tube wants cleaning. This tube can either be washed or cleaned with the scraper, according to circumstances, or, if necessary, taken out, but this should not be done more frequently than necessary; but, in order to make sure that the outer tubes will come out easily and rapidly, they should be removed every six months or every year, according to the nature of the water used.

If from any unusual cause the outer tube contains hard deposits, it can be slightly heated and moistened inside immediately; the deposits will then crack and come away completely, or they can be loosened by tapping lightly on the tube with a small hammer.

A tube should never be replaced until it has been thoroughly cleaned.

When the tube has been taken out in this way the interior can be the more easily inspected by removing the end nut with the same spanner and in the same way as the inner tube.

This end nut should seldom be removed, and never whilst the tube is in its place in the header. The outer tube should be taken out, held between the jaws of a vice in a collar made in two pieces, and the spanner only should then be used.

As regards the order of cleaning, the tubes of the lower rows should be taken out first, then the next above, and so on upwards. When putting them back the reverse order should be followed—*i.e.*, the upper rows put in first.

The interiors of the headers should be washed, and, if necessary, scraped, before the tubes are put back. If the outer tubes have been taken out they must be well wiped on the outside before they are put back.

The coned surfaces of the lanterns and of the collectors, as well as all the threaded parts, should be smeared, as they are taken out, with anti-oxidising grease in order to preserve them from rust.

No boiler is to be closed up until every tube which has been opened has been searched and the other parts of the boiler carefully examined by an engineer officer or by a trustworthy and competent chief petty officer.

Cleaning the Fireside of the Tubes under Steam.—If water be not used in the ashpits, it will only be necessary to clean the fireside of the tubes on long runs—*e.g.*, after three or four days' continuous steaming at 60 per cent. of the full power.

The tubes can be cleaned by a steam or air lance while the boiler is at work, the lance being inserted in the space between the headers. Cleaning by means of steam or air lances should only be done when fires are actively at work, and then care should be taken that the lance is well blown through before it is applied to the tubes; if this precaution is not taken, the soot on the tubes will be wetted and caked.

Scoriæ which accumulate on the bottom row of tubes can be removed, as far as practicable, by scrapers when the fires are being cleaned.

The upper part of the boiler should be cleaned first, working downwards, so that the soot deposited in each row, together with that which has fallen from the upper rows, can be cleared out.

This should be done as often as the nature of the fuel requires, usually once in every working day. It must not be forgotten that, as the soot impedes the transmission of heat, it necessitates greater consumption of coal to evaporate the same amount of water. Care should be taken to see that the fires are low, with only a thin layer of coal on the grates, before starting this operation.

As damp soot on tubes is liable to cause serious corrosion, it is important that the fireside of the tubes of boilers which are not under steam should be kept clean and dry. Accumulation of soot on the baffles is to be carefully removed when the tubes are cleaned.

It is not necessary to use either red lead or white lead for any of the special joints; and the use of these is absolutely forbidden. Nothing should be used for any of the joints except special grease for preventing oxidisation.

The steam drums should be opened up in order to make sure that all their different parts are in their places and in a good state of repair.

If the grease filters are not cleaned sufficiently often, greasy deposits may enter the steam drum. If such is the case, these deposits must be removed as completely as possible, and the boiler must then be boiled out with a solution of soda as described above.

Taking out the Tubes (Fig. 111).—The inner tube should be taken out in the manner previously indicated. Each outer tube is then taken out by means of the apparatus represented in Fig. 111:—

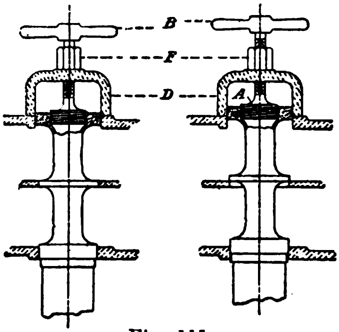

Fig. 111.

A. Threaded spindle which screws into the place occupied by the head of the inner tube.
D. Bridge.
F. Nut.
B. Handle on the threaded spindle.

When the inner tube has been taken out, the bridge D is placed against the header, the spindle A is then screwed by means of the handle B into the place of the head of the inner tube. The nut F is then tightened by means of a special spanner, care being taken that the bridge D bears well against the header. As soon as the nut F begins to bear against the bridge the tube comes out.

The apparatus for taking out the tubes is then taken off, unscrewing the spindle A by means of the handle B.

A pole is then passed into the tube, well to the end. This pole bears the weight of the tube while it is being pulled out by its head.

Care should be taken to turn it a little to right and left whilst taking it out, until the lantern is free of the header. *Immediately the tube is taken out its coned surfaces should be greased*, as well as those of the header.

If the *end nut* is taken off to enable the interior of the tube to be more easily seen, care must be taken to *immediately grease all the threads*. As the tubes are taken out of the boiler they should be laid on a plank, so that the machined surfaces do not get damaged.

If the tube contains any deposits, keep it full of water until just before it is to be cleaned, so as to prevent the deposits from hardening.

Before greasing the cones, the turned surfaces should be cleaned with a cloth or *very fine* emery paper. The headers are treated in the same way, and afterwards the coned surfaces are smeared with special grease, as before mentioned.

Replacing the Tubes.—The coned faces on both tubes and risers should be thoroughly cleaned and examined to see that they are free from burrs or other defects, the coned faces on the tubes should then be coated with anti-oxide grease and the tubes slid into place with the special rod provided, care being taken that the centre punch marks on the front connections which denote the position of the water-ways are kept in a vertical line. The tubes should then be tapped home with a small lead hammer, the dogs put on and the nuts moderately tightened up. Should there be any leaks under water pressure either of the coned joints or the front plugs, it may be necessary to further tap in the tubes or screw up the plugs, but in no case should any great force be required to make the joints tight, and if any difficulty is experienced it will be found that some foreign substance has got between the coned faces or the surfaces have got damaged, in either case the tube must be withdrawn, the faces cleaned and the joints remade.

Before steam is raised in any boiler which has had tubes removed and replaced or renewed, it is to be tested by water pressure to, at least, nearly the pressure at which the safety valves are loaded, and all the joints inspected for leakage during the time the pressure is on. When steam is being raised in the boiler for the first time after the tubes have been replaced or renewed, the joints should be examined with the steam pressure at about 50 lbs.; if any of the coned joints show signs of leaking the steam pressure must be dropped and the boiler emptied sufficiently to permit of the removal of the tubes of which the joints are leaking. The turned surfaces must be examined and any defects in them made good; if no defects are found, the surfaces must be cleaned and the tubes replaced.

No joint should be tightened under any circumstances whilst the boiler is under steam pressure, and the smoke-box doors should always be kept closed whilst the boiler is working.

The tubes should never be struck in order to drive them home in the header; the proper tools for putting them back should always be used.

If, whilst steaming, one of the boilers has run short of water, the lower tubes of the elements should be tested, and if any of them are bent or burnt, these tubes should be straightened out and subjected to hydraulic pressure; the result of this test will show whether these tubes can be used again.

The lower tubes of the boiler should be frequently examined, and if they are found to be bent to the extent of 1 inch they should be taken out and straightened.

Care should be taken, before putting back the different parts, to smear with the special grease all the threads and coned surfaces of the outer and inner tubes, plugs, headers, bi-conical joints, all the threads of the bolts of the dogs and of their nuts.

Generally speaking, the nuts of the dogs and the different parts of the boiler should be tightened *without effort, and no spanners should be used for this purpose except those made specially for the different parts.*

If the spanners used are too large the nuts will be tightened too much, and it will be difficult to loosen them again.

Brickwork.—Care must be taken to keep the brickwork which protects the front and sides of the boiler in good repair in order to avoid a rapid deterioration of the sheet-iron casings.

Banking Fires.—As a general rule, fires should be allowed to burn out when the engines are stopped, unless steam is likely to be required at a very short notice.

The banking of heavy fires is undesirable, for with closed furnace and ashpit doors it is liable to cause overheating and bending of the fire-bars and bearing-bars.

When it is considered essential to bank fires, they should be pushed to the back of the grate and kept light.

The boilers should be allowed to cool down gradually, and the fire doors and ashpit doors kept shut.

Precautions to be taken when Putting out the Fires.—When fires are put out no lighted coal must be allowed to remain in contact with the boiler casings, or the metallic parts will become oxidised, and this will soon damage the casings, and they should not be wetted at the time of putting out the fires, as this would cause the sheet-iron to buckle. They should always be kept slightly greased so as to protect them from oxidation, which takes place very rapidly in the warm damp air of the stokehold.

The polished parts of the doors and of the front panels should be treated in the same way.

If rust marks are seen anywhere, rub the place with fine emery and oil until the marks have disappeared.

As has been previously mentioned, keep all the polished parts well greased. For the black parts use a mixture of grease and lampblack.

Yarrow Boilers*—*Lighting Up.*—The boilers should be fillea to slightly below the usual water level, about 3 inches in the glass being sufficient.

The lifting gear of the safety valves should be examined and the valves moved off their seats before fires are lighted.

Raising Steam.—Steam should be raised slowly when the boiler is being heated for the first time or when the brickwork is newly repaired. The fires on all occasions of raising steam should be kept as thin as possible. The water gauges, steam gauges, drenchers (where fitted), and all other boiler fittings should be examined and tested: the feed pumps should be tried, hand feed checks opened, and a little water introduced into the boiler to make sure that the connections are quite clear.

Connecting Up.—The boiler should be connected up with great care, and the stop valve should be opened to such an extent as to give a small amount of wire drawing.

Management of Fires.—The fires should be about 5 inches thick with no air pressure in the stokehold, rising to 7, 8, and 9 inches, with pressures of $\frac{1}{2}$ inch, 1 inch, and $1\frac{1}{2}$ inches of water.

The coal should be well broken up and thrown on the grate quickly, the largest lump being not greater than a ball of about 4 inches diameter. To prevent the furnace doors being kept open longer than is necessary, two men should be employed for the operation of firing, the second man closing the door between separate shovelsful. The stoker should be taught to distribute the coal uniformly with the shovel, and the rake should only be used when the fires have become uneven, or to stir up the fires when increasing speed after being closed up for a time. Fires should be kept free of the dead-plate, and should be slightly thicker near the brickwork at the back and sides of the furnace.

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* See Admiralty Circular Letter of 4th November, 1904.

Water should only be used in the ashpits to a limited extent to keep the fire-bars from being burnt, for it should be borne in mind that too much water causes a deposit to form on the bottom row of tubes which cannot be removed by brushes, and has to be scraped off, besides causing considerable loss of heat.

Systematic Stoking.—It is essential to adopt a system of stoking by which the fires are frequently fed with light charges in a regular rotation, arranged so that adjacent furnace doors are not fired consecutively. For steady steaming the charge can be kept practically constant, say 3 or 4 small shovelsful at a time: at higher rates of steaming it is better to slightly increase the quantity of each charge to 5 or 6 shovelsful than to unduly diminish the interval and distress the personnel.

For ordinary service, the number of boilers in use should be arranged for a rate of combustion of 15 to 20 lbs. of coal per square foot of fire-grate per hour and no air pressure in the stokehold.

For full power steaming, the rate of combustion should not exceed 40 lbs. of coal per square foot of fire-grate per hour and an air pressure not exceeding 1½ inches of water, but in an emergency the fires may be forced to burn 60 lbs. of coal per square foot of grate per hour.

Draught Plates.—The draught plates should never be opened wide except to remove ashes, as not only are the best results obtained with the doors about three-quarters open, but it has been found that self-closing doors are liable to stick when in a horizontal position, thereby losing all the advantages derived from an automatic door in the case of a tube giving out, by failing to check the rush of steam, ashes, &c., into the stokehold.

Cleaning Fires.—The cleaning of fires should not be delayed too long, but should be commenced after eight to twelve hours' steaming, and, when burning 40 lbs. of coal per square foot of grate per hour, after four hours. The fires should be cleaned in the same order in which they are fired—three or four fires being cleaned each watch—so that all fires are cleaned in about sixteen hours, and it is better to clean a fire in each boiler in each watch than to clean one boiler right out. At all rates of combustion the fire-bars must be kept clear of clinker by the frequent use of the slice in the intervals between the cleanings of the fires.

Sweeping Tubes.—If water is used sparingly in the ashpits, it will only be necessary to clean the fire side of the tubes underway, on long runs, probably after three or four days' steaming. This can be done by inserting a steam or air lance through portable doors in the front of the boiler casing and working it up and down over the whole length of the tubes. It is advisable to clean the tubes over the fire that is to be cleaned, as then the soot and dirt which drop into the fire are soon removed, and do not choke up a clean fire. The deposit of scoriæ, which forms on the front of the fire rows of tubes under continuous forced draught, can only be removed completely with scrapers when the boilers are cold.

Stopping and Reducing Speed.—If the engines are suddenly eased or stopped, the steam production should be checked as much as possible by closing the ashpit doors, and, if necessary, opening the furnace doors; suddenly opening all the furnace doors is undesirable, and increasing the feed to any extent is liable to cause priming, as the water level rises in the boiler when the engines are again started. The silent blow-off should be used most carefully.

Banking Fires.—As a general rule, fires should be allowed to burn out, unless steam is required at very short notice, in which case the fires should be pushed to the back of the grate and kept light, the opportunity being taken to remove all dirt and clinker from the fires.

Feeding the Boilers.—The temperature of the feed-water should not be allowed to fall below 120° F.

Automatic feeding is not absolutely essential, but by feeding the boiler regularly a regular production of steam is obtained with greater economy. Where fitted, great care should be taken to keep the automatic gear in good working order.

If the feeding arrangements do not work properly, and the water disappears from the gauge, the fires should be checked immediately by closing the draught plates, and if the water does not promptly reappear the fires must be drawn and the boiler shut off. The boiler must not be worked again until it has been ascertained that there is no defect in the feeding apparatus, and that no defects have arisen in the boiler due to overheating.

The water in the boilers is to be kept slightly alkaline by the addition of lime water to the feed-water.

Every twenty-four hours a small quantity of water is to be blown out of the boilers by fully opening the scum cocks and bottom blow-out cocks for three or four seconds.

Shutting Off.—The fires should be allowed to burn down and the boiler to cool down gradually, the furnace and ashpit doors being kept closed; if the boiler is to be pumped up this should be done while the fires are dying out.

Preservation.—Boilers not in use are to be kept quite full of fresh water freed from air by boiling and made distinctly alkaline by an extra quantity of lime. Whenever it is possible, the boiler should be pumped up while the fires are dying out; but, when this cannot be done, or when empty boilers are pumped up, the water should be boiled to expel the air; care should be taken to ensure the boilers remaining quite full by pumping the boilers up to about 50 lbs. pressure in the first place, and making up any subsequent losses once a week.

To prevent damage in cold weather, the temperature of the water in the boilers should be kept up to at least 40° F. by the use of bogies or light fires in the grates.

Examination and Cleaning.—In ships in commission, the boilers should be thoroughly examined internally and externally once a quarter, special attention being paid to the condition of the zinc slabs and their connections. Partial internal inspection should also be made after a period of steaming; and this should include a thorough examination of the two fire rows of tubes on both sides of the grate. Boilers to be opened out for thorough cleaning are to be boiled out with a strong solution of common soda: allow 20 lbs. to a ton of water, and boil for at least twelve hours, allowing the steam to blow off through the safety valves at a pressure of about 40 lbs. The water level should be kept about an inch above the scum pan, and every two hours water should be blown out through the scum valve, which should be kept wide open until steam blows through; the bottom blow-down cocks should also be opened wide for about ten seconds, the loss being made up with fresh water. After the boiling out is finished and fires are drawn, the boilers should be blown out empty through the bottom blow-down cocks. All the tubes should be thoroughly cleaned internally with tight-fitting wire brushes, and the plates of the steam collectors and water pockets also thoroughly cleaned.

All the tubes are to be thoroughly cleaned externally as soon as practicable after the fires are out, and great care should be taken not to allow accumulations of soot and ashes on the water pocket tube plates.

The casing joints must all be kept perfectly tight, as leakage of air causes rapid destruction, and care must be taken not to allow any accumulation of ashes or coal dust in any portion of the casing.

The fire rows of tubes should be carefully examined and gauged for distortion, and any alteration recorded: a small gradual change of curvature is not important unless it is accompanied by a movement of the tube in the tube plate, in which case, as also in the case of leakage of tube joints, the tubes so affected should be carefully re-rolled. A sudden considerable bending of a tube or any bulging indicates the presence of internal deposits, and in these circumstances immediate cleaning is necessary. If the tubes are clean, the distortion may be due to the boiler not having been free to expand and contract under variations of temperature owing to the improper adjustment of the holding-down bolts. The nuts of these bolts should only just bear when the boiler is hot.

Isolated tubes not in the fire rows, which fail from any cause, should be plugged with the stoppers provided; if it is necessary to plug a tube which is not perforated—*e.g.*, a bulged tube—a hole must be made in the tube before the plugs are fitted in place.

The brickwork, especially that forming the arches over the furnace doors, must be frequently examined, and repaired as necessary, to guard against injury to the boiler casings.

To Remove a Tube.—Cut the tube through with a cross-cut chisel close to the top and bottom tube plates, and drive out the two pieces remaining in the tube plates into the collectors with a shoulder punch, taking care not to injure the holes in the tube plates.

To Replace a Tube.—The tube hole should be carefully cleaned with emery until the surface is bright, and the ends of the tubes should also be perfectly clean and dry and free from grease and scale. When the new tube is in, it should be lightly rolled before being bell-mouthed, after which it can be belled as required; any tube which exhibits any signs of fracture being immediately rejected. After bell-mouthing both ends, complete the expanding of the tube as required.

APPENDIX I

NEW SCHEME OF ENTRY OF NAVAL CADETS WHO ARE CANDIDATES FOR COMMISSIONS AS EXECUTIVE AND ENGINEER OFFICERS OF THE NAVY AND OFFICERS OF THE ROYAL MARINES.

(*Applicable at the Examination in July, 1904, and succeeding Examinations.*)

FOR THE INFORMATION OF CANDIDATES.

1. All officers for the executive and engineer branches of the Royal Navy or for the Royal Marines will enter the service in future as naval cadets under identical conditions, and will be educated and trained together until passing as Sub-Lieutenants.

2. Appointments to naval cadetships will be made by nomination, subject to the nominees passing a qualifying examination. Candidates who fail to pass will not be allowed a second trial.

No nomination will be given to boys whose parents or guardians do not declare for them that they are prepared to enter any one of the three branches of the service at the termination of their probationery period of service afloat.

As far as possible each officer will be allowed to choose which branch or service he will join, but this must be subject to the proviso that all alike are satisfactorily filled.

Candidates must be of pure European descent, and the sons either of natural-born British subjects, or of parents naturalised in the United Kingdom. If any doubt arises upon this question, the burden of clear proof that he is qualified will rest upon the candidate.

3. All nominations of candidates for naval cadetships are made by the First Lord,* with the exception of a limited number which are at the disposal of individual members of the Board, and of the secretaries to the Board of Admiralty.

4. Every candidate desirous of receiving a nomination from the First Lord of the Admiralty will be required to present himself before a committee which will sit at the Admiralty for the purpose of interviewing candidates shortly before the qualifying examination takes place. The fact, however, of a candidate being invited to appear before this committee is not to be understood as in any degree implying that he will necessarily receive a nomination.

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* Applications for nominations should be addressed to the Assistant Private Secretary to the First Lord, and should not be made until the candidate has reached 11 years of age.

5. The nominations will be made three times a year, a few weeks before the date fixed for the examination of candidates.

6. Candidates will be examined only once, but parents may choose whether they will send up their sons at the earlier or later of the two occasions upon which they will be eligible for nomination, on the distinct understanding that if nominated they are entered for the qualifying examination immediately succeeding the interview.

In the case of boys who have received nominations being prevented by illness from taking the qualifying examination, their nominations may be postponed till the next examination, if their age permits.*

Should they not be able to present themselves for examination within the limits so prescribed, they will be finally excluded from entering the Naval College.

7. The qualifying examinations will be held in March, July, and December, and the appointments will date from the 15th May, 15th September, 15th January following, respectively.

8. Candidates for examination in—

March	must be not less than 12 years and 4 months nor more than 13 years of age on the following		- 15 May.
July	Do.	do.	- 15 Sept.
Dec.	Do.	do.	- 15 Jan.

9. Every candidate must be in good health, and free from any physical defect of body, impediment of speech, defect of sight or hearing, and also from any predisposition to constitutional or hereditary disease or weakness of any kind, and in all respects well developed and active in proportion to his age. Before undergoing the literary examination he will be required to pass the medical examination according to the prescribed regulations, and must be found physically fit for the Navy.

10. The qualifying examination will be in the following subjects†:—

(1) English (including writing from dictation, simple composition and reproduction of the gist of a short passage twice read aloud to the candidates).

(2) History and Geography, with special reference to the British Empire.

(3) Arithmetic and Algebra (to simple equations). *N.B.*—Two-thirds of this paper will be in arithmetic.

(4) Geometry (to include the subject-matter of the First Book of Euclid, or its equivalent, with simple mensuration. The use of instruments is allowed).

(5) French or German with an oral examination, to which importance will be attached.

(6) Latin (easy passages for translation from Latin into English and from English into Latin, and simple grammatical questions).

The list of successful candidates will be published in alphabetical order.

11. For all cadets entered under these regulations the payment will be at the rate of £75 per annum for the period under training, to be paid every term in advance to the cashier of the Bank of England on receipt

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* Should any case occur where a candidate's age prevents his nomination being deferred, the Admiralty will consider whether special arrangements can be made for him to be examined by the Head Master of the Royal Naval College, Osborne, at the beginning of the ensuing term, if then well enough.

† This revised schedule came into force at the examination in July, 1904.

of claim from the Accountant-General of the Navy. But the Lords Commissioners of the Admiralty reserve the power of selecting from among the cadets entered at each examination, a limited number being sons of officers of the Navy, Army, or Marines, or of Civil Officers under the Board of Admiralty, with respect to whom the annual payment will be £40 only. In this selection their Lordships will have regard solely to the pecuniary circumstances of the cadet.

Applications for the reduced scale must be received at the Admiralty not later than 1st January, 1st May, and 1st September.

Parents or guardians are further required to make a private allowance of £50 per annum to cadets from the expiration of their period of training until they reach the rank of Acting Sub-Lieutenant.

12. In addition to the annual payments mentioned in the foregoing paragraph, the parent or guardian will be charged with the personal expenses incurred by the cadet for washing, repairing boots and clothes, pocket-money, &c.

13. The period of training in the training establishments will be four years; there will be three terms in each year. The first term of each year will be approximately from 15th January to 15th April, the second from 7th May to 7th August, and the third from 15th September to 15th December.

The vacations will be four weeks at Christmas, three weeks at Easter, and six weeks at midsummer.

14. It is to be distinctly understood that the period of training is a time of probation, and the parent or guardian of every cadet will be required to sign a declaration on the admission of the cadet, to the effect that he shall be immediately withdrawn on the receipt of an official request for his withdrawal. The Lords Commissioners of the Admiralty reserve to themselves full descretion to request the withdrawal of any cadet from the Royal Naval College, if after a sufficient trial he is in their opinion for any reason unsuitable for the naval service. This discretion will, as a rule, be exercised at the end of the first year, but the proficiency and progress of the cadets will be periodically determined, and they may be required, if necessary, to withdraw at a later stage.

15. (*a*) Reports of progress and conduct will be made to the Admiralty at the end of each year of the cadet's study.

(*b*) In all subjects of instruction the principle will be followed of giving merit marks for current work. At the end of each year of training the cadet's proficiency and progress will be determined, partly by examination, and partly by the marks gained for current work during the year.

(*c*) Cadets who fail to attain a certain standard, or who, for any reason, are considered unsuitable for the naval service, may be required to withdraw at any time.

This rule will apply to those who do not show an aptitude for naval life, as well as to those who make insufficient progress or whose constitution is weak, although no disease may have developed.

16. Cadets whose conduct is unsatisfactory may at any time be required to withdraw.

17. Cadets will, on passing out of the training establishments, rank according to the amount of sea time they obtain at their final examination taken in conjunction with the results of their current work during their course of training, and those who obtain equal amounts of sea time will rank in order of merit in which they pass out of the training establishments.

18. The parent or guardian of every cadet will be required to provide outfit under the regulations in force.

19. No pay will be allowed by Government to cadets in the training establishments. The pocket-money allowed to cadets will be charged to the parents.

20. On leaving the training establishments, cadets will go to sea. At the end of three years, and after passing the necessary examinations, midshipmen will be eligible to pass for Acting Sub-Lieutenant, and, on passing, will be discharged to the Royal Naval College, Greenwich.

21. On the conclusion of their examinations, Sub-Lieutenants will be distributed between the executive and engineer branches of the Navy and the Royal Marines.

APPENDIX II.

EXAMINATIONS BEFORE PROMOTION OF ENGINEER OFFICERS, R.N.

These examinations are made by senior engineer officers of the Fleet Reserve. The candidates are examined singly; the questions put are very varied, being those suggested by the experience of the examining officers. The examination is largely *vivâ voce.* The following questions are typical of those usually given, but the list is by no means exhaustive:—

1. Name all the appliances, pumps, &c., usually provided in a modern ship for clearing her of water in the event of a leak, and describe the principles of their action.

2. Describe and sketch a Bourdon pressure gauge, and the apparatus for testing it. How would you test a vacuum gauge?

3. Describe how you would proceed to ascertain the pitch of a screw propeller blade. (See p. 162.)

Describe any important defects you have experienced (*a*) in the main engines, (*b*) in the boilers; also the immediate and subsequent action taken to render the parts affected (or the machinery generally) efficient.

What steps would you take in the event of a piston-rod becoming hot? Would you apply a jet of water? What would probably be the result of such an application of water? (See p. 59.)

Describe any means you are acquainted with for shrinking a metal band, such as the tyre of a wheel, which has become enlarged so that it is insecure. Mention any parts of the machinery to which the process referred to might be usefully employed.

Note.—If the band be heated and then placed in water, so that only half its width is immersed, the part still hot will be compressed by the cooled portion. The process may be repeated, the other half of the width being immersed.

How would you proceed to discover the cause of a faulty vacuum? (See p. 55.)

What is an air vessel? How does it act? At what parts of an engine, or of its fittings, are air vessels generally applied?

Note.—An air vessel is fitted in the delivery pipe of force pumps, to equalise the velocity of the water discharged, and tends to produce a uniform discharge. Its function is similar to that of the flywheel of an engine—viz., to make the working of the machine as regular as possible.

To what causes do you attribute the cases of rapid corrosion of copper pipes, carrying salt water, which have been observed in certain ships?

Note.—It is conjectured that leaks from the electric circuit to the hull may temporarily increase the galvanic action between the copper and metals to which it is electronegative. It is also stated that the quality of the copper employed is sometimes responsible for the rapid deterioration.

Sketch and describe the method of passing steam pipes through a watertight bulkhead.

Explain why, in vertical engines, the centre of the slide valve does not coincide with the centre of the exhaust port when the valve is in its central position.

Note.—A common practice is to design such slide valves with equal laps at each end, when placed symmetrically on the slide face; to correct the effects of the "obliquity" of the eccentric and connecting-rods the valve is set up on the valve-rod by an amount equal to about one-fourth the mean lead. The point of cut-off on the up stroke is thus made later, and on the down stroke earlier, than before the correction. The lead at the bottom of the valve will be greater than that at the top, but it will still be found, in most cases, that the mean pressure on the down stroke is greater than that on the up stroke.

Sketch a set of indicator diagrams supposed taken from the cylinders of a triple expansion engine. Mark all particulars thereon. Show how these diagrams would be affected by:—

(*a*) Leakage past the H.P. slide valve.
(*b*) An earlier cut-off in the Int. P. cylinder.
(*c*) An earlier cut-off in the H.P. cylinder.
(*d*) Wiredrawing of the steam by the H.P. valve.
(*e*) Leakage past either of the pistons.
(*f*) Faulty setting of the valves.
(*g*) Faulty setting of either of the eccentrics.

What are the advantages to be derived from using steam of high pressure. Show by diagrams the advantage of using steam expansively.

Note.—See the supplement to the *Steam Manual*, p. 3, *et seq.*

Why is it more economical to use steam expansively in a series of cylinders, rather than to complete the expansion in one cylinder?

Note.—The engines of warships are designed to attain a rate of expansion at full power of about six when the initial pressure is 155 lbs. (gauge), and about eight when the initial pressure is 250 lbs. (gauge), after all losses are allowed for. If only one cylinder were used, the necessary point of cut-off would entail the use of a separate expansion valve, which is not desirable. If the expansion be carried out in stages, the range of temperature in each cylinder is a fraction of the whole, and the loss by initial condensation is smaller; also the loss due to clearance is reduced in this arrangement.

About how much fuel per indicated horse power per hour is required by modern steam engines, the expansion being (*a*) simple, (*b*) compound, (*c*) triple? Give examples with which you are acquainted. See pp. 8, 70.

About how much coal can be burnt per square foot of grate per hour in the various types of boiler with which you are acquainted? Give the particulars of each system of working.

Note.—With natural draught in return-tube boilers, about 28 lbs. per square foot per hour, and with about 1 inch of air pressure, 36 lbs., in Admiralty practice. In the water-tube boilers of destroyers as much as 75 to 80 lbs. per square foot per hour is burnt, the air pressure being 3 to 4 inches.

What proportion of the total heat generated by the complete combustion of the fuel in the furnaces of a marine boiler is converted into the useful work of propulsion? Give the approximate efficiencies (*a*) of the boiler, (*b*) of the steam, (*c*) of the mechanism, (*d*) of propulsion, and give a short account of the causes of loss in each case.

Note—The efficiency of a good marine boiler does not often exceed 70 per cent. The loss is occasioned by incomplete combustion, radiation, and the high temperature of the funnel gases on discharge.

The efficiency of the steam does not exceed about 17 to 20 per cent. in an engine designed to effect economy. The losses are due to the heat necessarily rejected in the condenser, to initial condensation, to clearance, to receiver drop, &c.

The efficiency of the mechanism may be taken as about 85 per cent., the loss being due to the friction of the bearings, and to the work absorbed by the air pump, &c.

The efficiency of propulsion does not exceed about 70 per cent., the loss being due to the "augment of resistance" caused by the propeller (see *White's Naval Architecture*, pp. 540, *et seq.*), and to the frictional resistance to the motion of the blades.
The resulting efficiency is then about 0·07 as a maximum.

If the speed of a ship when using only three boilers be 7 knots, what speed may be expected with four boilers?

Note.—The power may be supposed increased as 4 : 3. Also, we may assume power ∝ (speed)^3, consequently the estimated speed V is given by

$$\frac{V^3}{7^3} = \frac{4}{3}, \text{ and therefore } V = 7{\cdot}7 \text{ knots.}$$

If 400 tons of coal are sufficient for a given voyage at 10 knots, at what speed must the vessel steam to consume 300 tons for the voyage?

Note.—Let k = consumption per hour in tons, t = time of voyage in hours.
Then, consumption for voyage is $C = k\,t$. Let L = length of voyage.

Then, assuming $k \propto$ I.H.P., $C \propto \text{I.H.P.} \times t \propto V^3 \times \frac{L}{V}$

$$\therefore \qquad C \propto V^2 \times L$$

Consequently, required speed V is given by $\frac{300}{400} = \frac{V^2}{10^2}$, or $V = 8{\cdot}6$.

It should be noted that the assumption $k \propto$ I.H.P. is only true over a small range of speed; also the assumption I.H.P. $\propto V^3$ is true only at moderate speeds for any given ship.

Find the pitch required for a screw propeller to drive a ship at 11 knots when making 100 revolutions a minute, assuming the slip is 30 per cent.

Note.—If P be pitch in feet, R = revolutions per minute, s = slip, and S = speed in feet per minute, then $s = \frac{P \times R - S}{P \times R} = \frac{3}{10}$ $\therefore S = P \times R \times \frac{7}{10}$

Describe the composition and steaming qualities of each of the two following kinds of coal:—(*a*) Bituminous or North Country coal; (*b*) Welsh coal or anthracite. Mention the proper arrangements necessary for their favourable combustion.

Note.—The composition of Newcastle coal is generally about C = 0·82, H = 0·053, O = 0·057, S = 0·012, Ash, &c., = 0·058; that of Welsh anthracite is C = 0·84, H = 0·048, O = 0·041, S = 0·014, Ash, &c., = 0·057.

If the brick bridges in the furnace mouth are destroyed, what space would you allow for the passage of smoke when rebuilding them?

Note.—The proper space is ⅛ the grate area in Admiralty practice.

The composition of a certain coal is by weight as follows:—C = 0·795, H = 0·053, O = 0·087, Residue = 0·065. What is its theoretical calorific value, and what quantity of air will be required per lb. for its proper combustion in a boiler furnace?

Note.—Cal. value $= 14{,}500\left\{C + 4{\cdot}28\left(H - \frac{O}{8}\right)\right\}$ B.T.U.

Weight of air per lb. theoretically necessary $= 11{\cdot}6\left\{C + 3\left(H - \frac{O}{8}\right)\right\}$ lbs

In a certain engine the steam is exhausted at 10 lbs. pressure absolute (temperature 193° F.). Temperature of water in feed tank 100° F. How much circulating water must be pumped through the condenser, by the circulating pumps, for each lb. of steam condensed? Temperature of sea water, 60° F.; efficiency of cooling surface 0·8.

Note.—Heat rejected to condenser per lb. $= 193 - 100 + \left\{966 - \cdot 71\,(193 - 212\right\} = 1072\cdot5$ T.U.

Rise of temperature of circulating water $= \cdot 8\,(100 - 60) = 32^\circ$.

$$\therefore \qquad N = \frac{1072\cdot5}{32} = 33\cdot5 \text{ lbs. per lb. of steam.}$$

Where are thin plates to be looked for in a boiler when it wears, and how is the thinness to be detected? (See pp. 172, 255, 321.)

What parts of a marine tubular boiler are first injured by shortness of water?

Sketch and describe the construction of a glass water gauge mounting on a boiler, with its connections. How is it packed and what attention does it require when the boiler is in use?

Note.—See pp. 73, 74.

How is the leak from a split tube stopped in a boiler in use? Describe the operations necessary. (See pp. 188, 320.)

Sketch a marine boiler of "tank" type, giving a longitudinal section and front elevation without smoke-box doors. Explain how the several parts are designed and arranged to resist internal pressure. Give sketches showing the attachment of the various stays.

Suppose on making the drill test of a boiler you discovered a thin plate (*a*) in the shell; (*b*) in a flat surface; how would you ascertain the proper pressure at which the boiler should be worked?

Note.—In Admiralty practice the stress f allowed in the shell plates is 12 tons per sq. in. under the test pressure p; the latter is 90 lbs. greater than the working pressure, when the latter is above 90 lbs. per sq. in. Then, if t be the thickness of the plates, the rule is $t = \frac{p\,D}{2\,f\,e}$ where e is the efficiency of the joint, about 80 per cent.

For flat surfaces the rule is $P^2 = C\frac{t^2}{p}$; p is test pressure in lbs. per sq. in., t = thickness in $\frac{1}{16}''$, P'' is pitch of the stays, and C a const. depending on the attachment of the stays, if these be nutted on both sides of the plate, $C = 175$ to 200.

Name the principal deposits found in a boiler fed with salt water.

Why is it essential that the heating surfaces of boilers should be kept thoroughly clean?

State what you know of the causes of leaky tube ends in a boiler worked under forced draught with closed stokeholds.

Note.—Describe the benefit which follows the use of the Admiralty ferrule.

Mention any cases you are acquainted with in which defects in a boiler have resulted from improper application of stays. Explain how the arrangement differed from that usually found to be successful.

What particular difficulties have been experienced in double-ended boilers with a combustion chamber common to the furnaces at opposite ends?

Note.—Overheating of the tube ends occurred, caused by the high temperature at which the gases reached the tubes. If each furnace has a separate combustion chamber, the plate heating surface is greater, and the temperature of the gases at the entrance to the tubes is reduced; the extra water spaces provide a better water circulation.

Describe the proper measures to be taken for the care and preservation of boilers not in use. (See p. 167.)

Describe fully the matters requiring attention in the care and management of a particular type of boiler whilst under steam.

Describe the duties of an engineer of the watch on being ordered to raise steam (*a*) in connection with the boilers, (*b*) in connection with the engines.

Describe fully the duties of an engineer of the watch when steaming.

Explain and show by a sketch the manner in which a steering engine is controlled in order that it shall promptly follow the motions of the deck wheel. How would you proceed to "connect up" such an arrangement as you describe? (See p. 39.)

What precautions are necessary in the working of the capstan engine?

Note.—A certain limit of steam pressure must not be exceeded, because the engine is designed to give a certain maximum pull on the cable at that pressure. The thrust blocks may tend to warm up, and a water service should be arranged.

Why is water pressure preferred to steam pressure for working the mechanism of heavy guns? What are the relative advantages and disadvantages?

Mention the precautions to be observed in order to preserve the various parts of the hydraulic system from damage by frost.

Describe the principal features of a hydraulic pumping engine. Illustrate your description by sketches, showing a section of the pump and valve chambers.

In triple-expansion engines fitted with independent linking-up gear to each slide valve, describe the effect, on the total I.H.P. and the I.H.P. of each cylinder, of linking up each slide valve separately, other conditions remaining the same.

The effect of linking up the H.P. alone is to decrease the power of the engines. Linking up either the M.P. or L.P. slide alone decreases the power in the preceding cylinder by raising its back pressure, but increases the power in the cylinder linked up and does not alter the total I.H.P. of the engines.

Sketch and describe the packing in the stuffing-boxes of the piston-rods of the main and auxiliary engines of a modern battleship. (See pp. 129, 131, 342.)

If engines driven by Belleville boilers be suddenly eased, describe the effect on the water level in the gauge glasses on the boilers and of the automatic feed apparatus on the feed pumps. (See Supplement to *S.M.*)

Describe the method you would adopt, and the precautions to be taken, in fitting either the spare junk ring or a spare pair of crank-pin brasses in place. What clearances would you allow, under different circumstances, to be assumed and stated by yourself? (See pp. 106, 107, 108, 165.)

APPENDIX III.

REGULATIONS RELATING TO THE EXAMINATIONS OF ENGINEERS

Under the Merchant Shipping Act, 1894.

Qualifications for Certificates of Competency.*—**Second-Class Certificate.**—A candidate for a second-class engineer's certificate must be twenty-one years of age;

(*a*) He must have served an apprenticeship to an engineer for three years at least, and prove that during the period of his apprenticeship he has been employed on the making and repairing of engines; or, if he has not served an apprenticeship, he must prove that, for not less than three years, he has been employed as a journeyman mechanic in some factory or workshop on the making or repairing of engines. In either case he must also have served one year at sea in the engine-room as an engineer on regular watch in the foreign, home, or coasting trade†; or

(*b*) He must have served at least four years at sea in the engine-room as an engineer on regular watch in the foreign, home, or coasting trade.

(*c*) He must be able to give a description of boilers, and the methods of staying them, together with the use and management of the different valves, cocks, pipes, and connections.

(*d*) He must understand how to correct defects from accident, decay, &c., and the means of repairing such defects.

(*e*) He must understand the use of the barometer, thermometer, and salinometer, and the principles on which they are constructed.

(*f*) He must state the causes, effects, and usual remedies for incrustation, and corrosion.

(*g*) He must be able to state how a temporary or permanent repair could be effected in case of derangement of a part of the machinery, or total break down.

(*h*) He must write a legible hand, and understand the first five rules of arithmetic, and decimals, and their application to questions about consumption of stores, and full capacities of tanks and bunkers, the duty of pumps, and the direct strains in engines and boilers.

(*i*) He must be able to pass a creditable examination as to the various constructions of paddle and screw engines in general use; as to the details of the different working parts, external and internal, and the use of each part.

(*j*) He must possess a creditable knowledge of the prominent facts relating to combustion, heat, and steam.

First-Class Engineer.—A candidate for a first-class engineer's certificate must be twenty-two years of age.

In addition to the qualification required for a second-class engineer:—

---

* For the various qualifications accepted in lieu of those here given see the pamphlet on this subject published by Messrs. Wyman & Sons, Limited; price threepence.

† Two-thirds only of the length of service in the home or coasting trade is reckoned towards sea service.

(*a*) He must either possess or be entitled to a first-class engineer's certificate of service; or, in the event of his not being so possessed or entitled, he must have served for one year at sea as second engineer in a foreign-going steamship or a home-trade passenger steamship with a second-class engineer's certificato of competency valid in the United Kingdom, or for two years at sea as second engineer with a second-class engineer's certificate of service; or having served one year at sea as second engineer with a second-class engineer's certificate of service, he must show, in addition, at least six months' service as chief engineer in a vessel required by law to carry at least one engineer holding a certificate.

The examiner should therefore be satisfied that an applicant for a first-class engineer's certificate has not only been *in possession* of a second-class certificate for the periods above stated, but that he has actually *served* for such periods in the engine-room, at sea with a second-class certificate, in the capacities referred to, and that his name has been entered in the articles of agreement accordingly.

(*b*) He will be required to make an intelligible hand sketch, or a working drawing of some one or more of the principal parts of a steam engine, and to mark in, without a copy, all the necessary dimensions in figures, so that the sketch or drawing could be worked from.

(*c*) He must also be able to take off and calculate indicator diagrams.

(*d*) He must be able to calculate safety-valve pressures, and the strength of the boiler shell, stays, and riveting.

(*e*) He must be able to state the general proportions borne by the principal parts of the machinery to each other, and to calculate the direct stress, the torsional stress, and the bending stress in round bars, and the direct stress and the bending stress in rectangular bars with given loads.

(*f*) He must be able to explain the method of testing and altering the setting of the slide valves, and to sketch about what difference any alteration in the slide valve will make in the indicator diagram, and also the method of testing the fairness of shafts, and of adjusting them.

(*g*) He must be conversant with surface condensation, superheating, and the working of steam expansively.

(*h*) His knowledge of arithmetic must include the mensuration of superficies and solids, the extraction of the square root, and the application of these rules to questions relating to the power, duty, and economy of engines and boilers, and to the stresses in rods, shafts, and levers of engines.

Examination for an Extra or Honorary Certificate.—This examination is voluntary; it is held once in three months only, and extends over several days; notice must be given at least one week before the date of examination.

If the candidate passes he will receive the certificate at once, without being required to have served two years at sea with a first-class engineer's certificate of competency, as formerly.

(*a*) The candidate must possess a thorough knowledge of the construction and working of the different forms of marine engines and propellers in all their parts, and be so far acquainted with the elements of theoretical mechanics as to comprehend the general principles on which the machine works, and to illustrate his knowledge of these principles by numerical examples.

(*b*) He must possess a knowledge of the theory of strain and stress sufficient to be able to deduce the ordinary rules for the bending of rectangular bars, and for the twisting and bending of round bars.

(*c*) He must be acquainted with the principles of expansion and the modern theory of heat; and be able to solve, with the assistance of his own book or without books, according as the examination papers may be set, questions in economy and duty in connection with engines and boilers.

(*d*) He must understand how to apply the indicator, and to draw the proper conclusion from the diagrams, and to construct the approximate diagrams for any given data.

(*e*) He must be able to produce, without a copy, a fair working drawing of any part of the machinery, with figured dimensions fit to work from.

(*f*) He must understand the principles of the action of the screw propeller and the paddle wheel, and must be able to estimate numerically the effect, in speed of ship, and consumption of fuel, due to any alteration in pitch, diameter, revolutions, &c., &c.

(*g*) He must be able to give a description of boilers and the methods of staying them, and must show that he possesses a knowledge of the theoretical principles which regulate their construction, and that he is able to calculate the strength of the boiler shell, stays, and riveting.

(*h*) He must understand the general nature of the strains and stresses produced by the steam pressure, and by the expansions due to unequal temperatures in boiler shells.

(*i*) He must have a knowledge of safety-valve construction, and the principles involved in determining the size of a safety valve, and the construction of spring-loaded and dead-weight valves.

(*k*) He must possess a thorough knowledge of the theory of combustion; the chemical composition of fuels; the evaporative duty of fuels of given composition; the production of draught; the effect in regard to economy, safety, and wear and tear, of increasing or of diminishing the proportion of heating surface, of grate bar surface, of area of section of air passages, of area of water surface, of steam space capacity and water capacity.

(*l*) He must be able to explain the formation of scale and the precipitation of salt, and the precautionary means adopted in respect thereto, with jet condensers, and with surface condensers.

(*m*) He must understand the general principles involved in the construction of the barometer, thermometer, salinometer, and steam and vacuum gauges.

(*n*) He must be familiar with the general results obtained from past experience in relation to corrosion, pitting, and galvanic action in boilers, and the use of zinc and of soda in boilers.

(*o*) He must give a variety of illustrations of how defects have arisen from accident, imperfect construction, or deterioration, and how these defects might have been prevented, and the best way of repairing such defects.

(*p*) He must possess an intelligent knowledge of the properties of the lubricants, boilor cements, and indiarubber in general use in steamers.

(*q*) He must understand the causes of spontaneous combustion, and the formation of explosive gases in coal holds, and the precautionary measures proper to prevent accidents from these causes.

(*r*) The candidate may, with his application to be examined, send in questions set by himself and worked in his own way, without books. These must be forwarded to the chief examiner of engineers. This is to afford him an opportunity of showing to the best advantage what he knows. Questions based upon these examples will be afterwards put before him to test the soundness of that knowledge.

(*s*) To give scope to test the information and reasoning power of the candidate, the questions may be framed upon any well understood objects, such as are employed in text books to illustrate the action of some principle of engineering science.

Engineers and assistant engineers in the Royal Navy are at liberty to apply for certificates of service, and to be examined for certificates of competency in the mercantile marine; but the Lords Commissioners of the Admiralty have directed that the applications of officers on the active list should be made through their commanding officer, and that the applications of officers on half-pay should be made to the secretary of the Admiralty, who in either case will forward the application to the Board of Trade.

An assistant engineer, R.N., may be examined for a second-class certificate of competency, and an engineer, R.N., for a first-class certificate.

Temporary active service as engineer in the Royal Navy counts in applications for certificates of competency in the same way and to the same extent only as in the case of the service of mercantile marine engineers—that is to say, so much of the applicant's time as is spent in active service at sea, or in a ship commissioned for sea service, counts as "sea service"; and so much of the applicant's time as is spent in active service on board ship in harbour, and not commissioned for sea, counts as workshop time.

Service performed in the capacity of engine-room artificer may count to qualify a candidate for examination for a second-class engineer's certificate of competency in the mercantile marine. If the service has been on shore it will only count as workshop time. If in the engine-room at sea the candidate must prove that during such service he had charge of an engine-room watch.

For further information see the pamphlet entitled *Examination of Engineers*, Examination 16, printed by Messrs. Wyman & Sons, Limited, price one penny; also the books already mentioned, p. 25.

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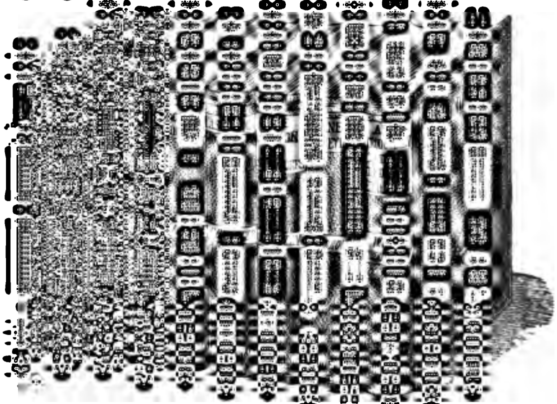

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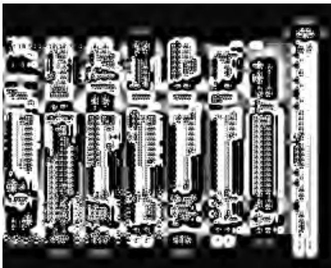

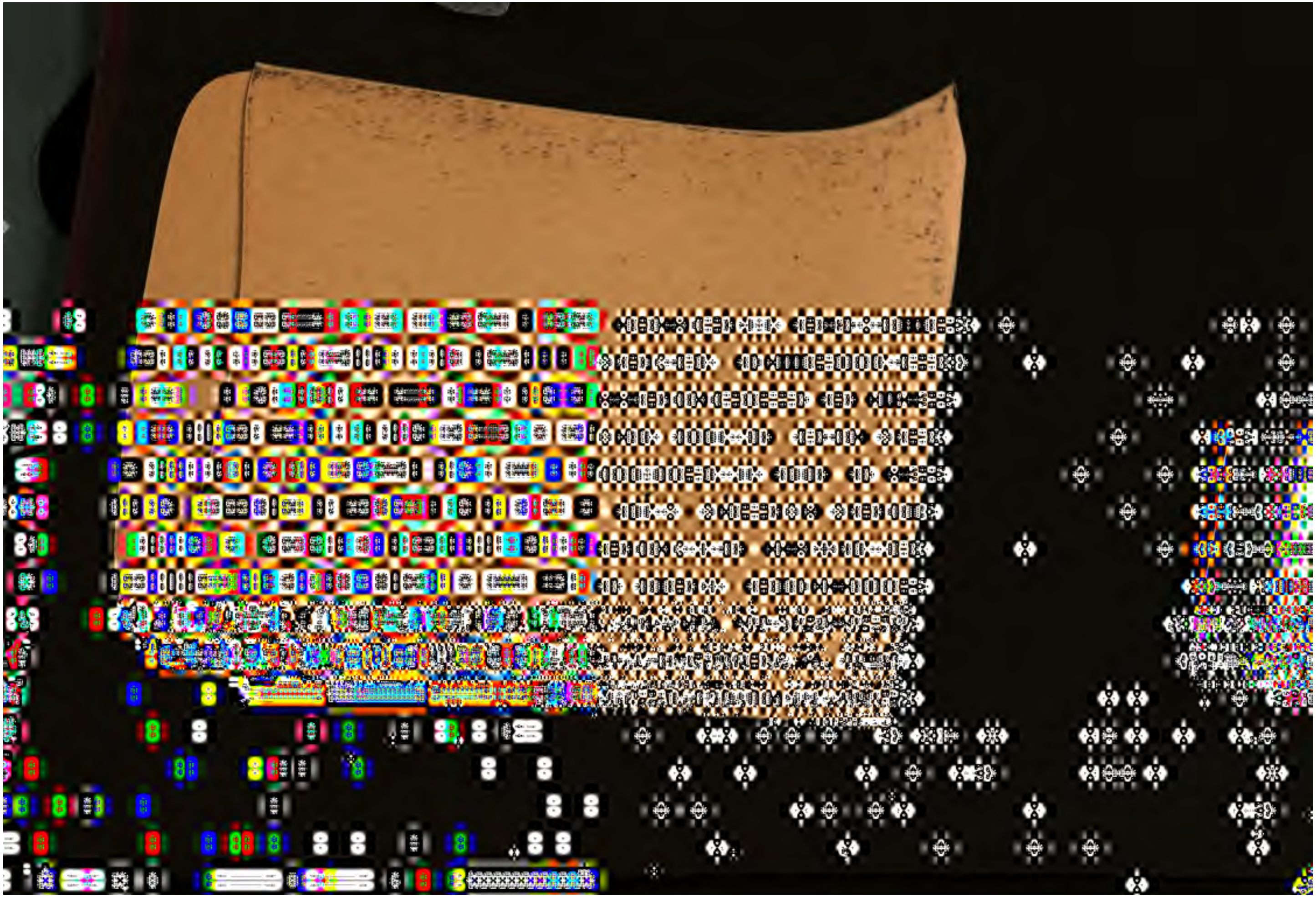

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